Ecological features of an outlying stand of jarrah
(*Eucalyptus marginata*) at Jilakin Rock, Western Australia

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Abstract

Features of a biogeographically significant stand of jarrah, about 115 km east of the nearest jarrah forest, are described. The stand represents a relict of formerly wider distribution. In 1981 129 individuals were located of which 43% had been killed by wildfire in 1967. No seedlings or saplings were found; the smallest tree found alive was of diameter 6.3 m. The largest trees in the stand reached 150 cm in diameter, similar to that in low quality jarrah forest. The stand is protected by its inclusion in an A class reserve. Future management of the stand will need to minimise the risk of wildfire.

Introduction

Jarrah, *Eucalyptus marginata* Donn ex Sm., is the dominant tree species of south-western Australia. It is found in the Darling Range more or less continuously west of a line from near New Norcia, Northam, York, Dryandra, Williams, along the Albany Highway to Cranbrook, within the Stirling Ranges and east to Beaufort Inlet (Beard 1976, 1979a,b,c; 1980a,b; Smith 1974). Churchill (1968) found several populations of jarrah isolated from the main range, though some result simply from the above described eastern boundary fragmenting into isolates of jarrah (see particularly Beard 1979c. 1980b; Smith 1974 and Lange 1960). The two most truly isolated populations are at Mt. Lesueur and Jilakin Rock. Both are separated from the main range of jarrah by about 115 km. The population at Mt. Lesueur occurs on lateritic soils around mesas and consists entirely of individuals of mallee from 2-3 m in height. That at Jilakin Rock comprises trees reaching a maximum height of about 24 m.

Although the occurrence of jarrah at Jilakin Rock has been on the public record for over 60 years (O'Connor 1918, Arboris 1933), there has been no scientific study made of the population. The aim of this paper is to describe the extent, population size and dimensions of the trees of the jarrah stand at Jilakin Rock; to compare the dimensions of these trees with those in low quality jarrah forest to the west; and to discuss the origin of the stand and its conservation status.

Table 1

Climatic data for Kulin and Lake Grace, climatic stations nearest Jilakin Rock.

Kulin (elevation 300 m)

	J	F	M	A	M	J	J	A	S	O	N	D	Y	No. Years
Kulin (elevation 300 m)														
Mean rainfall (mm)	11	17	23	24	51	61	56	43	29	22	15	12	364	59–60
Median rainfall (mm)	4	5	14	18	46	58	54	39	29	18	8	7	368	59–60
No. rain days	2	3	3	5	10	13	15	12	8	7	4	2	84	37–42
Lake Grace (elevation 288 m)														
Mean max. temp. (°C)	32·2	31·4	28·1	23·2	19·7	16·3	15·6	16·1	18·7	22·6	26·0	30·4	23·4	17
Mean min. temp. (°C)	14·8	14·7	13·4	11·0	7·8	6·7	5·5	4·8	6·0	8·3	10·5	13·2	9·7	17

Environment

Jilakin Rock is a large granitic dome nearly 340 m above sea level, or some 60 m above the surrounding plain (Fig. 1). It is situated 400 m west of Jilakin Lake and 16 km east of Kulin. Soils around the rock are sandy.

Rainfall data for Kulin Post Office are listed in Table 1. Temperature data are not available for Kulin. The nearest station is at Lake Grace, 50 km south of Jilakin Rock (Table 1).

Near the eastern margin of the jarrah forest, Baker's Hill, Narrogin and Kojonup have an average annual rainfall of 618, 507 and 546 mm respectively, considerably more than at Kulin. Mean maximum temperatures of the hottest month (January) range from 29.4 to 31.5°C at the eastern margin of the jarrah forest. Mean minimum temperature of the coldest month (August) varies from 5.0—6.0°C. Thus temperatures experienced at Lake Grace differ little from those near the eastern boundary of the jarrah forest.

Location and habitat of jarrah at Jilakin Rock

Jilakin Rock is surrounded by samphire vegetation to the east, around Jilakin Lake, and elsewhere shrubland and woodland almost 20 m in height. The jarrah population occurs amongst a compact stand of some large individuals of jam *Acacia acuminata* Benth., rock she-oak *Allocasuarina huegeliana* (Miq.) L. Johnson and York gum *Eucalyptus loxophleba* Benth. only on the fringe of the northern side of Jilkin Rock and along a small ephemeral watercourse running from the base of the rock for about 80 m (Fig. 1).

Fourteen trees were found in private property (Loc. 7759) along this watercourse. A road about 10 m wide crosses this creek, so it is likely that 5-10 trees were removed in the road-making. All remaining trees occur in Loc. 10087, part of A class reserve 15385. The approximate extent of the population is shown in Fig. 1. Clearly the distribution of jarrah downslope from Jilakin Rock is closely related to extra run off. The trees are naturally irrigated (Beard 1980a). None of the other granite bosses near Jilakin Rock (Fig. 1) have jarrah trees at their bases.
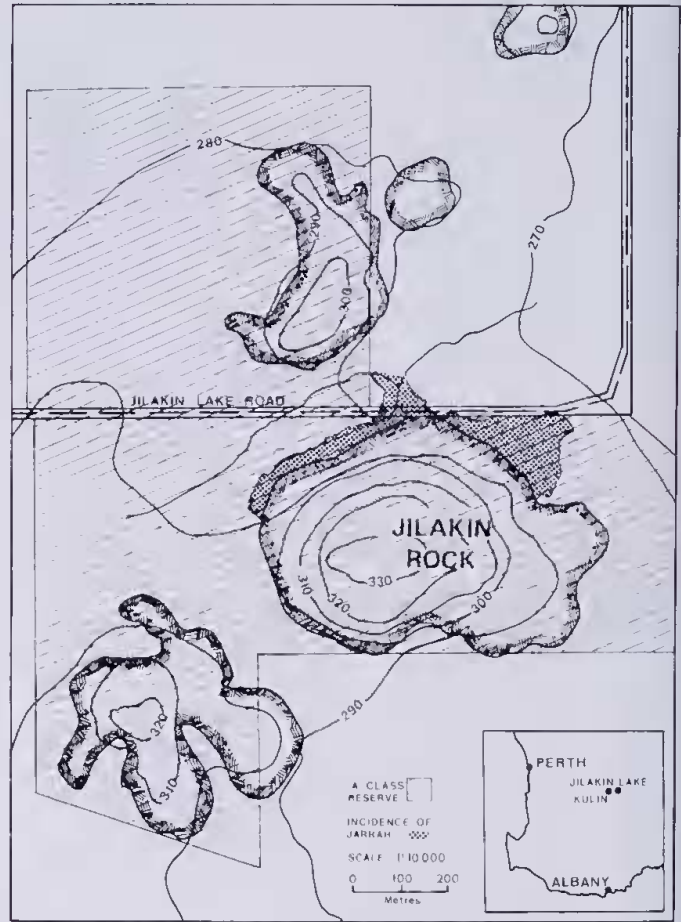

Figure 1.—The distribution of jarrah at Jilakin Rock.

Table 2

Frequency distribution of diameter* of the jarrah population at Jilakin Rock.

Diameter overbark 1·3 m above ground (cm)	No. alive	No. dead	% dead within each diameter class†	% dead of total dead
6·3– 9·9	4	3	43	5
10– 19·9	15	19	56	35
20– 29·9	11	17	61	31
30– 39·9	16	9	36	16
40– 49·9	12	1	8	2
50– 59·9	....	1	....	2
60– 69·9	4	....	....	....
70– 79·9	3	1	....	2
80– 89·9	....	1	....	2
90– 99·9	....	....	....	....
100–109·9	....	....	....	....
110–119·9	....	....	....	....
120–129·9	....	....	....	....
130–139·9	....	....	....	....
140–149·9	1	1	....	2
Not measured	8	2	20	4
Totals	74	55	43	101

* Diameter of largest stem per lignotuber.   † Calculated only if sample size of diameter class >5.

Table 3

Frequency (%) distributions of diameter of jarrah stands in low quality forest and at Jilakin Rock

Locality	Site-vegetation type*	Plot size (ha)	No. trees	Diameter overbark (cm)														
				10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–110	110–120	120–130	130–140	140–150	150–160
Coondle	HZ	4·05	352	—	30·4	19·0	15·3	15·3	9·4	6·0	2·6	0·6	0·6	0·3	0·3	0·3	...	...
Beraking	HZ	4·05	398	—	27·6	12·6	15·5	13·9	8·5	9·3	7·3	1·3	2·8	0·8	0·3	0·3	...	...
Beraking	Z	0·41	75	—	53·3	21·3	10·7	2·7	2·7	1·3	4·0	...	2·7	...	1·3	...	...	...
Dale	HM	0·41	44	—	29·5	36·4	25·0	4·5	2·3	...	...	...	2·3	...	...	...	...	...
Dale	H	0·41	38	—	28·9	18·4	13·2	7·9	7·9	13·2	2·6	5·3	2·6	...	...	...	...	...
Cooke	ZP	0·41	41	—	22·0	22·0	24·4	7·3	12·2	2·4	7·3	2·4	...	...	...	...	...	...
Clare	Z/HZ	2·63	229	—	11·8	13·5	17·9	19·7	13·5	7·4	5·7	6·1	1·7	1·3	0·4	0·4	...	0·4
Leona	Z	0·41	41	51·4	63·4	19·5	7·3	4·9	...	...	2·4	2·4	...	...	...	...	...	...
Bell	ZM	0·20	37	18·8	13·5	10·8	13·5	5·4	2·7	2·7	...	...	...	...	...	...	...	...
Yourdamung	F	0·40	32	8·3	18·8	10·4	9·4	9·4	9·4	15·6	9·4	...	...	6·3	...	...	3·1	...
Surface	Z	0·40	48	30·4	4·2	...	18·8	10·4	29·2	8·3	4·2	4·2	...	2·1	...	...	...	...
Jilakin Rock	NA	NA	112	...	25·0	22·3	11·6	0·9	3·6	3·6	0·9	...	...	...	...	0·9	0·9	...
Jilakin Rock	NA	NA	78	...	35·9	32·1	16·7	1·3	5·1	5·1	1·3	...	...	...	...	1·3	1·3	...

NA—Not Applicable.   *After Havel (1975)

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Number and size of individual trees

In October 1981 I measured the diameter at 1.3 m above ground of nearly all of the jarrah trees at Jilakin Rock. Most consisted of multiple stems coming from a common lignotuber, in which case I always measured the stem of largest diameter at breast height. In a few cases where trees had fire scars or were otherwise damaged at breast height I measured diameter 1.6 m or 1.9 m above ground level. In all, 129 trees were located, of which 119 were measured as just described.

Nearly half of the trees were dead. As all of these had charcoal present on bark, I conclude that fire was responsible for the deaths (Table 2). Fire scars and other damage caused by fire were noted on half of the 20 trees with diameter exceeding 40 cm. According to B. A. Parker, occupier of adjacent Locations 7759 and 6319, there has been one fire only in the jarrah stand since he settled at Jilakin in 1921. This was in 1967 (Greble 1979).

No seedlings or advance growth (small saplings < 1.3 m high) were present in 1981 and none of the trees was in bud, flower or fruit. This was in marked contrast to November 1932 when A. C. Harris (unpublished data) recorded the trees seeding heavily. He also noted a dense crop of young seedlings as well as dense clumps of sapling-pole size trees. It is unlikely that the area was grazed between 1932 and 1981 because surrounding farms are fenced.

Comparisons with low quality jarrah forest

A considerable body of information is available for low quality jarrah forest. Height of mature codominant trees rarely exceeds 25 m, being usually less than 20 m (Havel 1975, Abbott and Loneragan 1983). The frequency distribution of diameters is generally of the form of a negative exponential (Table 3). Most of the plots when measured were uncut, but for those that had been cut over diameters of stumps (adjusted to 1.3 m above ground) have been included. As the lower limit for diameter was either 10 cm or more often 20 cm, the Jilakin data have been calculated for both criteria. For stems above 10 cm or 20 cm, the diameter distribution of the Jilakin jarrah stand is typical of much of the low quality jarrah forest.

However, the absence of seedlings and advance growth from the Jilakin population is quite different from the low quality forest where seedlings and saplings are abundant (pers. obs.).

A study of the growth rate of the Jilakin jarrahs has not been made. Several plots in the nearest jarrah forest, Dryandra State Forest, were established in 1976 and remeasured in 1981. These yield an annual increase in diameter underbark of 0.12 cm, although the sample size of eleven trees is very small. Notwithstanding that, a rate of 0.12 cm yr^{-1} agrees well with the figure of 0.11 cm yr^{-1} derived from a more widely based study of growth rate of jarrah in low quality forest (Abbott and Loneragan 1983). On this basis, over the period 1910-1981 jarrah trees at Jilakin Rock would have increased their diameter underbark on average by only 8 cm.

Origin of the stand

Three different origins of the stand have been proposed. The first and least likely is an aboriginal myth and is detailed by Arboris (1933). A. C. Harris in 1929 (unpubl.) suggested that seeds of jarrah had been carried to Jilakin Rock accidentally by aborigines "either in skins, or perhaps in their hair". Jilakin Rock was once a meeting place for aborigines who penetrated inland during each winter, returning to the coast each summer as water became scarce. The scientifically most favoured explanation is due to Churchill (1968). Changes in climate, particularly over the last 10 000 years, resulted in the eastern boundary of the jarrah forest fluctuating. In a period wetter than the present this boundary would have extended as far east as Jilakin Rock. One difficulty with this view is that no other granite rocks between Jilakin Rock and the present eastern margin of jarrah forest are known to support adjoining populations of jarrah.

Conservation status of the stand

The jarrah population at Jilakin Rock is part of A class reserve 15385 for parklands and water. Cutting of timber is prohibited. It was gazetted in 1914 after the occurrence of the stand was drawn to the attention of the Surveyor-General. Two of the largest sound trees were cut down before then, probably in 1910 as Loc. 7759 adjacent to the jarrah stand was fenced in October 1909.

Wildfires present a threat. Agricultural land surrounds the stand, resulting in the presence of many weeds. The wildfire of 1967 killed 57% of all stems less than 30 cm in diameter. Thus it is the smaller size classes that are most vulnerable to wildfire. The stand probably should be managed by regular burning with low intensity fires, as is the bulk of the jarrah forest, so as to minimize the risk of wildfire.

References

Abbott, I. and Loneragan, O. (1983).—Growth rate of jarrah (*Eucalyptus marginata*) in relation to site quality in cut-over forest, Western Australia. *Aust. For.*, 46: 91-102.

Arboris (1933).—Jarrah at Jilakin Rock. West Australian, 18 February.

Beard, J. S. (1976).—The Vegetation of the Newdegate and Bremer Bay areas Western Australia. Vegmap Publ., Perth.

Beard, J. S. (1979a).—The Vegetation of the Perth area Western Australia. Vegmap Publ., Perth.

Beard, J. S. (1979b).—The Vegetation of the Pinjarra area Western Australia. Vegmap Publ., Perth.

Beard, J. S. (1979c).—The Vegetation of the Albany and Mt. Barker areas Western Australia. Vegmap Publ., Perth.

Beard, J. S. (1980a).—The Vegetation of the Corrigin area Western Australia. Vegmap Publ., Perth.

Beard, J. S. (1980b).—The Vegetation of the Dumbleyung area Western Australia. Vegmap Publ., Perth.

Churchill, D. M. (1968).—The distribution and prehistory of *Eucalyptus diversicolor* F. Muell., *E. marginata* Donn ex Sm., and *E. calophylla* R. Br. in relation to rainfall. *Aust. J. Bot.*, 16: 125-151.

Greble, W. E. (1979).—A Bold Yeomanry: Social Change in a Wheat Belt District, Kulin 1848-1970. Creative Research, Perth.

Havel, J. J. (1975).—Site-vegetation mapping in the northern jarrah forest (Darling Range). 1. Definition of site-vegetation types. *Bull. For. Dep. W.A.*, 86: 1-115.

Lange, R. T. (1960).—Rainfall and soil control of tree species distribution around Narrogin, Western Australia. *J. Roy. Soc. W.A.*, 43: 104-110.

O'Connor, W. H. A. (1918).—Out of zone jarrah trees at Jeelakin. Western Mail, 11 January.

Smith, F. G. (1974).—Vegetation Map of Collie. W.A. Dep. Agriculture.

Epidermal characteristics of some Western Australian wandoo-woodland species for studies of herbivore diets

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Abstract

Characteristics of the epidermis of plant tissues can provide sufficient differences for separation at least at the generic taxonomic level. The comparisons of known samples with residual fragments of leaf cuticles in faeces provides a non-lethal method of determining the diets of herbivores. This current paper describes the methods employed to establish a voucher series for plants at the Yalanbee Experimental Station for a study of the food resources of the western grey kangaroo.

Three preparation techniques were compared on the wandoo-woodland plant specimens. The chromic acid/nitric acid digestion method gave the best results for most Western Australian native species. For the more mesic native shrub species and the introduced and native grass species, the acetic acid digestion method proved more successful in providing clean specimens of these species within cuticles. Imprint methods generally provided prints of inadequate detail for use in identifying the residual fragments from the faecal remains.

A diagnostic key using epidermal characteristics provided a method to extend the techniques of faecal fragment identification to use by non-specialised technical assistants.

Introduction

Studies of the diets of herbivores date from at least the mid-eighteenth century when, according to Tribe (1950), Linnaeus reported on the preference shown by farm animals for certain plant species. For almost the next two centuries the techniques used for the study of herbivore diets were dominated by those used for domestic animals in enclosed situations. Most of these techniques had practical limitations or were impossible to apply to open grazing and other less intensive farming practices. A developing interest in the food preferences of game and other non-domesticated animals led to new techniques for the study of food habits. One of these techniques was the identification of fragments of leaf epidermis from faeces (Baumgartner and Martin 1939, Dusi 1949). Except for vascular bundles, fibrous strengthening material and cutinized epidermal tissue, little plant material remains recognizable in faecal material (Phillipson 1952). Only the cuticle and its epidermal imprint has sufficient characteristics to be identified as belonging to a specific species.

The literature on dietary studies utilizing epidermal characters has been accumulating over the past 40 years (Dusi 1949, Stewart 1965, Kok and Van der Schijff 1973) and detailed accounts of the characteristics of the epidermal structures of monocotyledons (Metcalfe 1960, Clifford and Watson 1977) and dicotyledons (Metcalfe and Chalk 1950) have provided extensive background information. However, it was not until Storr (1961), Kiley (1966) and Stewart (1965, 1967) that the full potential of faecal analysis was realised in determining the feeding habits of wild and rare animals. Studies of the dietary preference of Australian macropods are limited (Kirkpatrick 1965, Griffiths and Barker 1966, Griffiths *et al.* 1974, Davis and Ellis 1979) and such studies in Western Australia are restricted to those of Storr (1961, 1964) on the quokka. Faecal analysis was used to gain further knowledge about the diet of the western grey kangaroo at the CSIRO Yalanbee Experimental Station in the wandoo (*Eucalyptus wandoo* Blakely) woodland-pasture landscapes near Bakers Hill. This method was the only practical option available, because the animals of the experimental station were part of a population dynamics study and could not therefore be killed to determine dietary resources through analysis of stomach contents. Because no previous work on the diet of the grey kangaroo had been attempted in the wandoo woodland, epidermal tissue vouchers had to be initially developed. The following report describes the development of methods for the preparation of plant epidermi, the nomenclature of epidermal characteristics for the series of voucher specimens, and the diagnostic key used in the western grey kangaroo dietary study (Halford *et al.* 1984.)

Epidermial tissue preparation

A number of techniques have been developed to prepare epidermal tissue for microscopic analysis. Once high-quality voucher specimens are available, the subsequent identification of epidermal fragments in animal faeces is made possible. These preparation techniques can basically be categorised into direct and indirect methods. Direct methods usually involve the removal of the leaf surface from the remainder of the plant material by bacterial disintegration, mechanical scraping, peeling or chemical maceration. Bacterial disintegration of the tissue (Louw *et al.* 1949, Skoss 1955) involves the breakdown of the tissue below the cuticle using certain microorganisms which digest the material with an enzyme complex of cellulases, hemicellulases and pectinases. Following a period of time the cuticle is mechanically lifted from the partially digested tissue. The major difficulty of the method is the time (often 14 days) required to obtain material and the specialized media requirements and anaerobic growing conditions for the bacteria.

Epidermal peeling (Dusi 1949) and mechanical scraping (Metcalfe 1960, Clarke 1960) involve the removal of the epidermal layer directly, as one might remove the peel of a ripe plum, or by gradually scraping the leaf tissue from the cuticle. These methods are time-consuming and difficult to apply where the epidermis is thin and closely associated with fibrous material, or where the leaves are ridged and furrowed, as in many Australian sclerophylls. The chemical maceration techniques utilize a variety of solutions to macerate tissue in order to free the cuticular layer membrane. Discussion and literature references for many macerating techniques are available (e.g. Sinclair and Sharma 1971). Generally these methods use mixtures and various concentrations of several weak acids, or hydrogen peroxide and a base as potassium hydroxide. Most of these methods are adequate in clearing the cuticle fragments from any remaining mesophyll or fibrous material, but the concentration of solutions, timing of various digestion periods and subsequent stain techniques often vary with the type of leaf material to be prepared. The major advantage of the direct method is that they can give a clear representation of the cuticle; however, the procedures may be time-consuming.

The indirect methods involve applications of liquid plastics or latexes which, upon drying to a thin, transparent film, can be peeled off and examined under a microscope. The materials used include Duco cement (William 1973), acrylic plastics (Horanic and Gardner 1967), cellulose acetates, Bennett and Furmidge 1956), polyvinyl alcohol (Mueller *et al.* 1954), mucilage and latex (Shah and Gopal 1969), and silicone rubber (Idle 1969). Indirect methods are generally much quicker and simpler to apply than the direct methods, but the quality of the epidermal reproduction is usually inferior.

Materials and methods

Three methods were examined to ascertain the most successful method for species of the wandoo-woodland vegetation. These included the indirect method of Horanic and Gardner (1967) and the direct methods of Storr (1961) and Jain (1976).

In the Horanic and Gardner method, a 6:6 mixture of Rhoplex AC-33 acrylic polymer emulsion was initially applied to the surface of the leaf and allowed to dry for 10 minutes. Two additional coats using full-strength Rhoplex were applied at 10 minute intervals and allowed to dry for 40 minutes. The emulsion was then removed and transferred to a microscope slide. Generally the imprints did not give adequate representation of the epidermi of a large number of the sclerophylls. It was unable to show any detail of ridged or deeply furrowed leaf surfaces and abaxial surfaces of leaves with revolute margins. The preparation was difficult to apply to terete leaves because the resulting film was curved and difficult to view under the light microscope or photograph.

Applying the method or Storr (1961), leaves were cut into 5 mm squares or, if leaves were small, they were trimmed along one edge to facilitate epidermal removal. The material was placed in a solution of equal parts 10% chromic acid and 10% nitric acid and carefully boiled in a fume hood until epidermal separation occurred. A dilute KOH solution was used to rinse the tissue before the cuticles were removed from remaining fibre and vascular tissue. Pieces of the epidermis were transferred through a graded series of ethanol from 10-95%, then stained with 0.1% gentian violet in 95% ethanol. Staining time varied with the material and ranged from 30 sec. to to 24 h. The stained tissue was transferred to absolute ethanol and mounted in euparal. Storr's technique gave good results for a broad range of the Western Australian species, excepting those species which had thin cuticles, where features were difficult to distinguish.

Using the method of Jain (1976), material was cut into 5 mm squares and allowed to stand in a 30% glacial acetic acid in water solution at 80°C for 24 h. The material was then washed with water, cleared of remaining fibrous tissue and dehydrated through the series of ethanol solutions to 95%, and stained in 0.1% gentian violet in 95% ethanol before mounting in euparal. Jain's method did not thoroughly clear the epidermis of the more sclerotic leaves, such as *Hakea trifurcata* and *Acacia celastrifolia*. It did, however, prove to be very successful in producing clean epidermi from grasses and the native species with more mesic leaves such as *Phyllanthus calycinus*.

Microphotographs of the best preparations were made at low magnification (30x). The photographs were taken with a Zeiss photo-microscope using Microfile Pan film.

To analyze the faecal material, a dried pellet was gently boiled for 15 min in a solution of equal parts 10% chromic acid and 10% nitric acid. After maceration, the material was filtered and rinsed several times with a dilute KOH solution, then stained with a 0.5% solution of gentian violet in 95% ethanol for 48 h. The stained fragments were mounted onto microscope slides in euparal. The fragment material could then be compared to the vouchers of suspected diet plants to determine the food resources actually ingested.

Epidermial character nomenclature

The epidermis of leaves has a number of characteristics which are useful in identification and classification of plants. In the field of palaeobotany, microscopic features of the epidermis (as they are reflected in the cuticle), have long been recognized as an aid in the study of fossil leaves (Bornemann 1856 cited by Dilcher 1974). Stace (1965) has shown how leaf epidermal features can be used to support other taxonomic aids, especially in the classification of the Combretaceae. More recently, Bongers (1973) used epidermal character in the taxonomy of the Winteraceae. Also epidermal characters have been applied as a safeguard against fraudulence in commercial stock feed (Parkinson and Fielding 1930 cited by Martin 1955), and police departments have found the epidermis useful in plant identification (Dilcher 1974). Useful epidermal characters used in the identification of fragmentary material include: cell orientation, stoma complexes, dermal appendex, and other epidermal cells.

Cell orientation

Storr (1961) in his faecal analysis work found the orientation of the epidermal cells to be a very useful diagnostic feature. The distinctive orientation of the epidermal cells along the longitudinal axis of the leaf is commonly observed in monocotyledons (Fig 1a), and is rare among dicotyledons where these cells are more irregularly distributed (Fig 1b). This basic pattern difference readily discriminates between these two large groups and can be beneficial in distinguishing relative proportions of grazing and browsing material eaten by herbivores.

Stoma complexes

The appearance of the stomata, especially with reference to the nature and orientation of neighbouring cells, is a frequently used taxonomic character (Metcalfe and Chalk 1950, Van Cotthem 1970). Dilcher (1974) has provided a series of terms relevant to the stomatal cell complexes which have proven helpful in the identification of epidermal tissue fragments (Fig. 1). The stomata complex of monocotyledons are commonly of the paracytic type. However, types such as tetracytic and anocytic have also been observed (Metcalfe 1961, Stebhins and Khush 1961). An added feature of the stomata complexes in monocotyledons is the shape of the subsidiary cells. These cells range from triangular to parallel-sided forms through intermediates to dome-shaped cells (Metcalfe and Chalk 1950). A species usually has a mixture of domes with either triangular or parallel-sided types, but it is very unusual to find triangular and parallel-sided types together (Clifford and Watson 1977).

In dicotyledons, the more common stomata complex types are anomocytic, anisocytic, paracytic and diacytic. Storr (1961) suggested that the first three are the most commonly observed types in Australian species. Potential variation does exist and Metcalfe (1960) warns that stomatal types of more than one kind sometimes occur together on the same leaf surface, or stomatal complexes on the upper and lower surfaces may not be alike.

Storr (1961) also suggests that stomata pore orientation may be useful as a diagnostic feature, but this appears to be of restricted use.

Dermal Appendages

All outgrowths of the epidermis are categorized under the term 'dermal appendage'. There is an enormous diversity of external appendages in the dicotyledons, but this is not exhibited as extensively in the monocotyledons (Metcalfe 1960). Radford et al. (1974) summarizes the types of epidermal appendages under three main headings including 'simple' trichomes which can be uniseriate or multi-seriate, compound trichomes of several forms and glandular trichomes. The features of length, size and density of the trichomes are more liable to vary with environment than the occurrence of different kinds (Sharma 1975). These characters should be avoided because of their questionable value for identifying epidermal fragments of different species. The presence or absence, however, can be of assistance. Gray et al. (1969) have demonstrated that the presence or absence of hairs between two closely related varieties of *Danthonia* was not environmentally induced, as the hairs were found to persist under a variety of controlled environments and transplant studies.

Other epidermal cells

The epidermal areas between the leaf veins (intercostal) and the tissue over the veins (costal) in monocotyledons sometimes have two cell types distinguishable by their size. Much elongated cells called 'long cells' tend to occur in intercostal regions, while more equidimensional cells called 'short cells' tend to occur only in the costal regions. In some grasses such as *Bromus* the short cells are absent (Metcalfe 1960). In others, such as *Coelachne* and *Mibora,* the distinctions tend to break down, which reduces their value as diagnostic features. Short cells also may contain a silica body or walls which give a cork reaction and the number occurring together or the arrangement may be of diagnostic value. The walls of the long cells of grasses can vary from straight and clear to very sinuous and clearly pitted. Also, the relative length and breadth can be of some value, but is subject to considerable variation.

The cells of dicotyledons are less regular than those found in the monocotyledons. The abaxial surface in some dicotyledons may be completely devoid of trichomes or stomata. There is generally, however, sufficient difference in the cells of different species to be of potential taxonomic value when looking at a limited number of species, as in faecal analysis study at the Yalanbee Experimental Station (Halford et al. 1984).

Intraspecific variation

It is important to differentiate environmentally modifiable features from those controlled genetically. Esau (1960) has noted that features such as the number of stomata per unit area, and whether guard cells are raised or lowered when compared to other epidermal cells, are so variable that they are of little taxonomic value. Characteristics such as a stomata frequency, epidermal cell frequencies and trichome densities generally vary with growing conditions. On the other hand, characteristics such as the type of stomatal complexes, distribution pattern of trichomes and types of trichomes tend not to vary with the environmental conditions and are, therefore, of greater value as diagnostic features in studies examining dietary preferences.

Wandoo-woodland vouchers

Of these species of the natural woodland regions and the pastures of the Yalanbee Experimental Station, slides of 60 species were produced of suitable quality for comparisons to the fragmentary material from the faeces of the grey kangaroos resident in the area. The voucher slides, enlarged photographs and descriptions of the important epidermal features of these species were used to prepare the diagnostic key to the more common species found in the faecal samples (Table 1).

All monocotyledons from the study area had stomatal apertures along the longitudinal axis of the leaf. Examples of Australian natives were *Neurachne alopecuroides, Lepidosperma tenue* and *Loxocarya flexuosa*. The introduced Mediterranean grasses of the pasture area also exhibited this pattern. Although this feature was rarer in the dicotyledons, it was observed in *Calothamnus sanguineus, Adenanthos cygnorum, Astroloma pallidum* and *Stackhousia hueglii*. In *Casuarina* the stomatal aperture was perpendicular to the long axis of the needle. No other dicotyledon showed regular orientation of the stomatal apertures.

Epidermal Cell Orientation
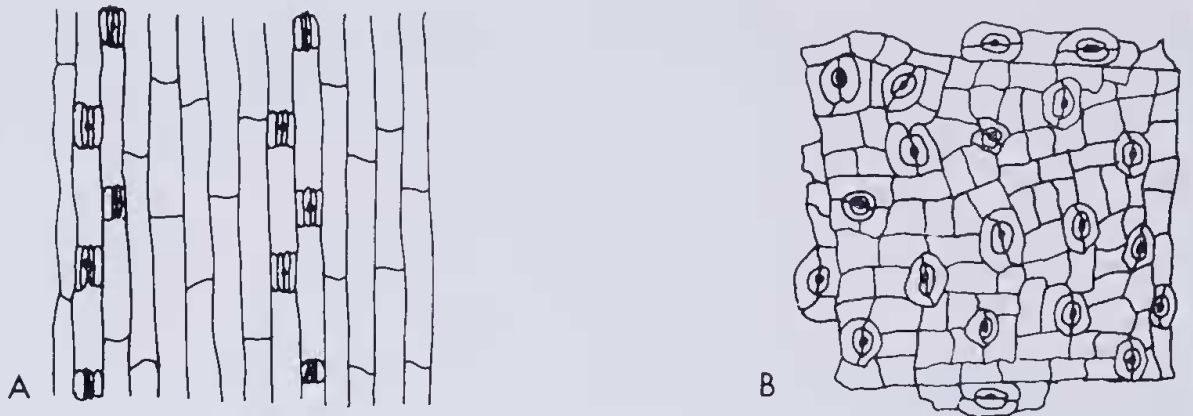
Stamatal Complex Types
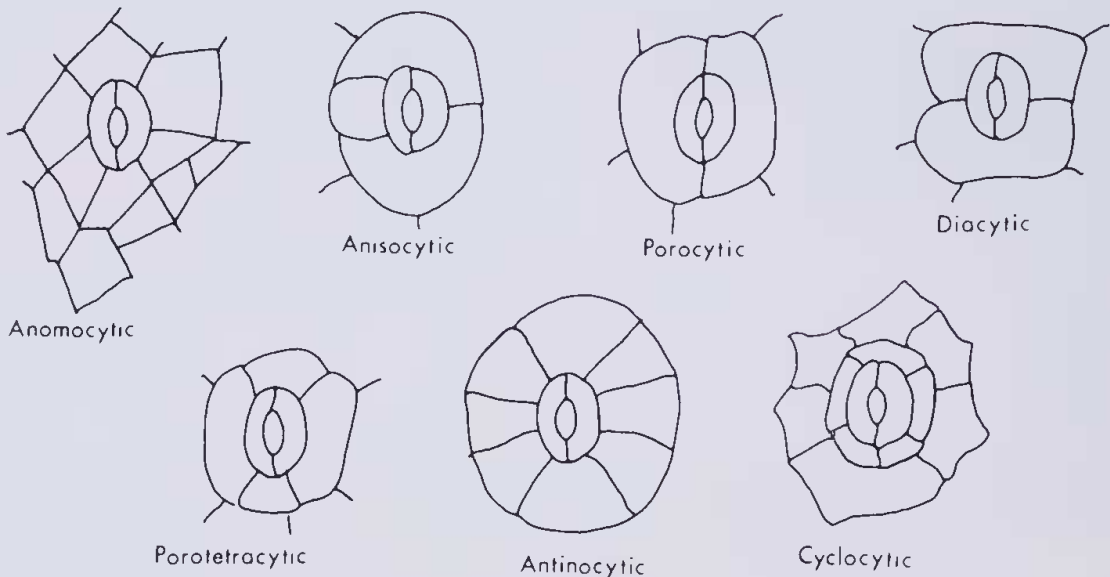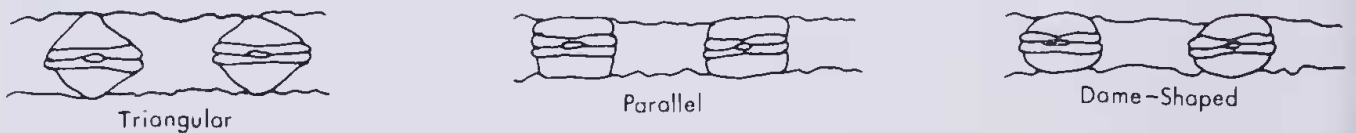

Subsidiary Cell Variation

Figure 1.—Epidermal tissue variation. Epidermal cell orientation in: (A) a monocotyledon (*Bromus rigidus*) shownig longitudinal orientation of epidermal cells and (B) a dicotyledon (*Acacia celastrifolia*) showing irregular orientation. Stomatal complex type nomenclature of angiosperm leaves (after Radford *et al.* 1974) and subsidiary cell variation of monocotyledons (after Metcalfe 1960).

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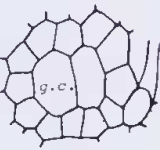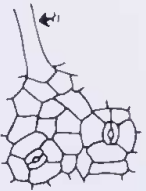
The nature and orientation of the subsidiary cells of the stomata proved to be especially diagnostic in the separation of the dicotyledonous species at the Yalanbee Experimental Station. The anomocytic stomatal arrangement, where cells surrounding the stomata are indistinguishable from normal epidermal cells, was found in *Hibbertia hypericoides*, *H. montana*, *Astroloma pallidum* and *Olearia rudis*. The anisocytic arrangement of three distinct subsidiary cells enclosing the stomata was observed in *Boronia crenulata*, *Hemigenia canescens* and *H. pimelifolia*. The paracytic arrangement of two

Table 1.

Key to the identification of selected native species in the Yalanbee Experiment Station woodland region using epidermal characteristics.

A.   EPIDERMAL CELLS LONGITUDINALLY ORIENTATED

    B.   EPIDERMAL CELLS RECTANGULAR (LENGTH:WIDTH RATIO >> 1:1) .... CONOSTYLIS SETIGERA

    BB.   EPIDERMAL CELLS MORE-OR-LESS ISODIAMETRIC (LENGTH:WIDTH RATIO =1:1) .... LOXOCARYA FLEXUOSA

AA.   EPIDERMAL CELLS USUALLY IRREGULAR IN ORIENTATION

    B.   TRICHOMES OR HAIR PRESENT

        C.   TRICHOMES SCATTERED

            D.   STOMATAL CELL COMPLEXES PARACYTIC ...... OR ANISOCYTIC ......

                E.   EPIDERMIS WITH GLANDULAR CELLS (G.C.) SURROUNDED BY RING OF TYPICAL EPIDERMAL CELLS .... LEPTOSPERMUM ERUBESCENS

                EE.   EPIDERMIS LACKING GLANDULAR CELLS

                    F.   STOMATAL COMPLEXES IN ± LINEAR ARRANGEMENT, HAIRS (H) EASILY BROKEN (H')DURING PREPARATION......... . ADENANTHOS CYGNORUM

                    FF.   STOMATAL COMPLEXES IRREGULAR IN ARRANGEMENT, HAIRS ROBUST AND PERSISTENT .... BORONIA CRENULATA

        DD.   OBVIOUSLY SUBSIDIARY CELLS ABSENT (I.E. ANOMOCYTIC) (NB. *CALOTHAMNUS SANGUINEUS* MAY SHOW PARACYTIC FORMS ALSO)

            E.   GLANDULAR CELLS PRESENT..... .... CALOTHAMNUS SANGUINEUS

            EE.   GLANDULAR CELLS ABSENT, EPIDERMAL CELLS WITH PAPILLOSE PROJECTION COMMON .... OXYLOBIUM PARVIFOLIUM

        CC.   TRICHOMES CLUSTERED IN CIRCULAR DEPRESSIONS WITHIN THE INTERCOSTAL REGIONS .... DRYANDRA SPP.

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BB. TRICHOMES ABSENT

    C. STOMATAL CELL COMPLEXES ANTINOCYTIC .... HAKEA SPP.

    CC. STOMATAL CELL COMPLEXS NOT ACTINOCYTIC

        D. STOMATAL COMPLEXES ARRANGED IN DEFINITE BANDS

            E. STOMATAL BANDS = 2X WIDTH OF COSTAL REGIONS,
               STOMATA IN ONLY A FEW LINES .... ASTROLOMA PALLIDUM

            EE. STOMATAL BANDS ≫ 2X WIDTH OF COSTAL REGION,
               IN NUMEROUS LINES .... CONOSPERMUM GLUMACEUM

      DD. STOMATA COMPLEXES NOT IN BANDS

        E. STOMATAL CELL COMPLEXES CELLS ANOMOCYTIC OR ANISOCYTIC (SEE BELOW)

            F. SUBSIDIARY CELLS ANOMOCYTIC

               G. GUARD CELLS SUNKEN .... HOVEA CHORIZEMIFOLIA

               GG. GUARD CELLS NOT SUNKEN .... GOMPHOLOBIUM MARGINATUM

            FF. GUARD CELL COMPLEXES ANISOCYTIC

               G. GUARD CELLS SUNKEN .... DAVIESIA CORDATA

               GG. GUARD CELLS NOT SUNKEN .... ANTHOCERCIS LITTOREA

        EE. STOMATAL COMPLEXES PARACYTIC

            F. SUBSIDIARY CELLS ± EQUAL IN SIZE

               G. EPIDERMAL CELL WALLS ± STRAIGHT, GUARD CELLS
                  ± SQUARES IN OUTLINE .... GASTROLOBIUM SPP.

               GG. EPIDERMAL CELL WALLS ROUNDED OR SLIGHTLY
                  UNDULATING, SUBSIDIARY CELLS ± TRIANGLAR... . SYNAPHAEA PETIOLARIS

            FF. SUBSIDIARY CELLS UNEQUAL IN SIZE .... ACACIA CELASTRIFOLIA

subsidiary cells parallel to the long axis of the stomata was recorded in all species of the genus *Gastrolobium* and all of the monocotyledon species studied. *Adenanthos cygnorum*, and all species of *Casuarina* also had the paracytic arrangement. All species of the genus *Hakea* examined had the anomocytic arrangement of stomata surrounded by radially elongated subsidiary cells. *Calothamnus sanguineus* was found to have a combination of anomocytic and paracytic types. In other species, such as *Grevillea pilulifera* and all the *Dryandra* species prepared, the stomata were not discernible, due to a dense mat of trichomes covering the stomata.

Stomatal distribution in the plants of the Yalanbee Experimental Station study site also provided a diagnostic character. A regular distribution of the stomata over the epidermal surface was observed in *Acacia celastrifolia, Calothamnus sanguineus, Adenanthos cygnorum* and *Hakea undulata*. Certain species had stomata arranged in distinct repeated patterns. This included the stomata of *Lepidosperma tenue, L. scabrum* and *L. angustatum* where the stomata were arranged in rows oriented along the longitudinal axis. In most of the species of the grasses, the stomata occurred in well-defined longitudinal bands in the intercostal zones. Each intercostal zone included one or more stomatal band depending on the species.

Stomata in some species tended to be associated with epidermal pits and furrows. The stomata of the *Dryandra* species studied were confined to depressions on the abaxial surface of leaves. The stomata of leaves of *Lomandra caespitosa* and *L. effusa* and the stems of *Opercularia vaginata, Casuarina humilis, C. heugeliana* and *Dampiera lavandulacea* were limited to longitudinal grooves.

Trichomes occurred in many of the species sampled from the wandoo woodland. Simple unicellular trichomes were present in *Boronia crenulata, Melaleuca holosericea, Leptospermum erubescens,* and *Hemigenia canescens*. *Adenanthos cygnorum* had simple unicellular trichomes but was distinguished by a large, flat, basal cell to the trichome. *Hibbertia hypericoides* had sessile stellate hairs and *Hemigenia canescens* had glandular and bicellular hairs. All of the species of *Dryandra* in the study had lociform trichomes densely covering the abaxial surface. *Calothamnus sanguineus* had setaceous trichomes, but these tended to break down during preparation of the epidermi. Several species had papillose projections from the epidermal cells. These included *Gastrolobium calycinum* and all of the species of *Casuarina examined*. The grasses tended to have mostly unicellular trichomes, which were not valuable in the identification of individual species.

Shape of the epidermal cells was helpful in distinguishing monocotyledons from dicotyledons. The cells of the monocotyledons were typically rectangular, with the length parallel to the longitudinal axis of the leaf. Some intermixed of the monocotyledons, however, were square. The dicotyledons varied from the isodiametrical cells as in *Dryandra sessilis* to more rectangular cells as in *Opercularia vaginata*. Irregular shaped cells in

Calothamnus and occasional paired cells separated by a sinuous wall in *Calothamnus* and *Leptospermum* were diagnostic. *Loxocarya flexuosa, Astroloma pallidum* and some of the grasses were also distinguishable from other species by sinuous epidermal cell walls. Other plants had typically straight walls with varying degrees of curvature at the corners.

In general, most of the plant epidermi from the Yalanbee Experimental Station study area had enough difference to allow identification to genera. However, within some genera, such as *Hakea*, the identification of epidermal fragments to a single species was not always possible. Even so, through careful preparation of faecal material and voucher specimens, it has been possible to develop a basis for studying the dietary preferences of the western grey kangaroo in the wandoo woodland-pasture landscapes of the Yalanbee Experimental Station. With the aid of the key it is possible to examine material rapidly and identify the common species being grazed.

References

Baumgartner, L. L. and Martin, A. C. (1939).—Plant histology as an aid in squirrel food-habits studies. *J. Wildl. Manage.*, 3: 266-268.

Bennett, S. H. and Furmidge, S. G. (1956).—Impression methods for the study of the distribution of deposits and organisms on plant surfaces. *Nature*, 178: 152-153.

Bongers, J. M. (1973).—Epidermal leaf characters of the Winteraceae. *Blumea*, 21: 381-411.

Bornemann, J. G. (1856).—Über organischer reste der lellenkoklengruppe thuringens ein beitray zur favena unde flora dieser formation der jetzweltlichen cycadeegattunger. IX. 85, 12 tab., Leipzig (Verl. Wilch, Engelman). (Original not seen).

Clarke, J. (1960).—Preparation of leaf epidermis for topographic study. *Stain Tech.*, 35: 35-39.

Clifford, H. T. and Watson, L. (1977).—Identifying Grasses: Data, Methods and Illustrations. University of Queensland Press, St. Lucia.

Davis, T. J. and Ellis, B. A. (1979).—Comparison of the diets of Yellow-footed Rock Wallabies and sympatrick herbivores in Western New South Wales. *Aust. Wildl. Res.*, 6: 245-254.

Dilcher, D. L. (1974).—Approaches to the identification of angiosperm leaf remains. *Bot. Rev.*, 40: 1-57.

Dusi, J. L. (1949).—Methods for the determination of food habits by plant microtechniques and histology and their application to cotton-tail rabbit food habits. *J. Wildl Manage.*, 13: 295-298.

Esau, K. (1960).—Anatomy of Seed Plants. Wiley International, New York.

Gray, J. R., Quinn, J. A. and Fairbrothers, D. E. (1969).—Leaf epidermis morphology in populations of the *Danthonia sericea* complex. *Bull. Torrey Bot. Club*, 96: 525-530.

Griffiths, M. and Barker, R. (1966).—The plants eaten by sheep and by kangaroos grazing together in a paddock in south-western Queensland. *CSIRO Wildl. Res.*, 11: 145-167.

Griffiths, M., Barker, R. and MacLean, L. (1974).—Further observations on the plants eaten by kangaroos and sheep grazing together in a paddock in south-western Queensland. *Aust. Wildl. Res.*, 1: 27-43.

Halford, D. A., Bell, D. T. and Loneragan, W.A (1984).—Diet of the western grey kangaroo (*Macropus fuliginosus* Desm.) in a mixed pasture-woodland habitat of Western Australia. *J. Roy. Soc. W.A.* 66: 119-128.

Horanic, G. E. and Gardner, F. E. (1967).—An improved method of making epidermal imprints. *Bot. Gaz.,* 128: 144-150.

Idle, D. B. (1969).—Scanning electron microscopy of leaf surface replicas and the measurement of stomatal aperture. *Ann. Bot.,* 33: 75-76.

Jain, K. K. (1976).—Hydrogen peroxide and acetic acid for preparing epidermal peels from conifer leaves. *Stain Tech.,* 51: 202-204.

Kiley, M. (1966).—A preliminary investigation into the feeding habits of the waterbuck by faecal analysis. *East African Wildl. J.,* 4: 153-157.

Kirkpatrick, T. H. (1965).—Food preferences of the grey kangaroo (*Macropus major* Shaw). *Queensland J. Agric. Animal Sci.,* 22: 89-93.

Kok, P. D. F. and Van der Schijff, H. P. (1973).—A key based on epidermal characteristics for the identification of certain high veld grasses. *Koedoe,* 16: 27-43.

Louw, J. G., Williams, H. H. and Maynard, L. A. (1949).—A method for the study in vitro of rumen digestion. *Science,* 110: 478-480.

Martin, D. J. (1955).—Features of plant cuticles: An aid to the analysis of the natural diets of grazing animals. *Trans, Proc. Bot. Soc. Edinburgh,* 36: 278-288.

Metcalfe, C. R. (1960).—Anatomy of Monocotyledons. Oxford University Presse, London.

Metcalfe, C. R. and Chalk, L. (1950).—Anatomy of the *Dicotyledons.* Oxford University Press, London.

Mueller, L. W., Carr, P. H. and Loomis, W. E. (1954).—The submicroscopie structure of plant surfaces. *Amer. J. Bot.,* 41: 593-600.

Parkinson, S. T. and Fielding, W. L. (1930).—The Microscopic Examination of Cattle Foods. Headley Brothers. London (original not seen).

Phillipson, A. T. (1952).—The passage of digesta from the abomasum of sheep. *J. Physiol.,* 116: 84-97.

Radford, A. E., Dickinson, W. C., Massey, J. R. and Bell, C. R. (1974).—Vascular Plant Systematics. Harper and Row Publishers, New. York.

Shah, G. L. and Gopal, B. V. (1969).—Preparation of epidermal imprints of living plant organs by the use of non-toxic mucilage and latex. *Stain Tech.,* 44: 123-126.

Sharma, G. K. (1975).—Altitudinal variation in the leaf epidermal patterns of *Cannabis sativa. Bull. Torrey Bot. Club.,* 102: 199-200.

Sinclair, C. B. and Sharma, G. K. (1971).—Epidermal and cuticular studies of leaves. *J. Tenn. Acad. Sci.,* 46: 2-11.

Skoss, J. D. (1955).—Structure and composition of plant cuticle in relation to environmental factors and permeability. *Bot. Gaz.,* 117: 55-72.

Stace, C. A. (1965).—Cuticular studies as an aid to plant taxonomy. *Bull. British Museum Nat. Hist. Bot Ser.,* E-3: 1-78.

Stebbins, G. L. and Khush, G. S. (1961).—Variation in the organization of the stomatal complex in the leaf epidermis of monocots and its bearing on their phylogeny. *Amer. J. of Bot.,* 48: 51-59.

Stewart, D. R. M. (1965).—The epidermal characters of grasses with special reference of East African plains species. *Botanische Jahrbücher,* 84: 63-174.

Stewart, D. R. M. (1967).—Analysis of plant epidermis in faeces: A technique for studying the food preferences of grazing herbivores. *J. Appl. Ecol.,* 4: 83-111.

Storr, G. M. (1961).—Microscopic analysis of faeces of technique for ascertaining the diet of herbivorous mammals. *Aust J. Biol. Sci.,* 14: 157-164.

Storr, G. B. (1964).—Studies on marsupial nutrition. IV. Diet of the Quokka, *Setonix brachyurus* (Quoy and Gaimard), on Rottnest Island, Western Australia. *Aust. J. Biol. Sci.,* 17: 469-481.

Tribe, D. E. (1950).—The composition of a sheep's natural diet. *J. British Grassland Soc.,* 5: 81-91.

Van Cotthem, W. R. J. (1970).—A classification of stomatal types. *J. Linn. Soc. Bot.,* 63: 235-246.

William, J. A. (1973).—A considerably improved method for preparing plastic epidermal imprints. *Bot. Gaz.,* 134: 87-91.

Diet of the western grey kangaroo (*Macropus fuliginosus* Desm.) in a mixed pasture-woodland habitat of Western Australia

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Abstract

The late autumn/early winter diet of western grey kangaroo living in a landscape of native wandoo open forest surrounded by pasture grasslands was assessed using faecal analysis. Eventhough some animals were observed regularly feeding in the pastures at night, a considerable number of native woodland species appeared in their diet in addition to the exotic pasture species. Thirty-one taxa of native plants were recorded from grey-kangaroo faeces. Of the native species, *Conostylis setigera, Opercularia vaginata, Bossiaea eriocarpa* and *Casuarina* spp. were the most frequently encountered in the faecal preparations. The frequency of pasture grasses appearing in the faecal material increased following the first winter rains which resulted in good pasture growth. Apparently kangaroos travel considerable distances to graze or browse on favoured species. Higher nitrogen content of certain favoured native species is hypothesized as contributing to this preference.

Introduction

European settlement of Australia has had a profound effect on the members of the Macropodidae. Some species have been driven to extinction, while others have increased in numbers due to favourable habitat changes (Calaby 1971). Changes in vegetation due to grazing stock have generally improved the habitat for the red kangaroo (*Megaleia rufa* Desm.) in many parts of its range and populations have greatly increased in numbers (Frith 1964, Newsome 1965). The western grey kangaroo (*Macropus fuliginosus* Desm.) and eastern grey kangaroo (*Macropus giganteus* Shaw) have disappeared from heavily settled areas but their numbers can be high in some pastoral districts.

At present the large macropods are variously viewed as pests whose population size should be controlled, objects of aesthetic pleasure and should be protected, or a valuable wildlife resource worthy of exploitation and conservation. Each of these views requires the development of a suitable management programme. To accomplish the aims of any management programme, there must be some manipulation of the environment or the animal population (Main 1968). The first step in the research programme to establish a management plan data base is to understand the relationship between the organism and its environment. Social organisation, habitat choice, food habits and the ecophysiology of the organisms are just some of the areas which need to be considered.

The ecology of a resident population of western grey kangaroo in a mixed landscape of native woodland and pastoral lands on the CSIRO Yalanbee Experimental Station at Bakers Hill, Western Australia is currently being studied (G. Arnold, pers. comm).

The grey kangaroos at the Yalanbee Experiment Station spend much of the day in a 90 ha area of native woodland. Spotlighting and a system of camera and electric-eye monitored fence openings indicate that numerous kangaroos feed in the pasture lands adjacent to the native woodland (G. Arnold, unpublished data). However, little is known of their feeding behaviour in the native woodland area. Objectives of this current study were to document the natural vegetation of the grey kangaroo residence area at the Yalanbee Experiment Station and to determine information on the kinds of food resources the animals are exploiting.

Study site

The Yalanbee Experiment Station at Bakers Hill, Western Australia (31°45'S, 116°27'E) lies 90 km north-east of Perth and 26 km south-east of Northam. The climate is Mediterranean with mild wet winters and hot dry summers. Twenty year averages from the station indicate a mean annual precipitation of 625 mm, with the highest mean monthly values occurring in June and July, both at 86 mm. Average maximum temperatures range from 17°C to 34°C in July and January, respectively. Summer daily maxima over 40°C are common. Mean monthly minima range from 17°C in January to 4°C in July.

Topographic relief of the study area is low, with a range of approximately 150 m (Fig. 1a). Soils in the study area include the Yalanbee, Kauring and Malebelling soil series (Fig. 1b). Yalanbee soils ocupy the highest landscape positions and are predominantly yellowish-brown ironstone gravels. Kauring soils are shallow, overlying granitic rocks which are exposed in some areas. Malebelling soils consist of light-brown gritty loamy sand with some ironstone gravels toward the base over yellow and reddish-brown mottled sandy-clay loam with rock fragments.

Vegetation

The Yalanbee Experiment Station lies within the Wandoo Woodland vegetational region (Gardner 1942). The regional dominant is *Eucalyptus wandoo*. Depending on habitat conditions, *E. accedens, E. marginata, E. calophylla* and *Casuarina huegeliana* can also be common species of the woodland canopy stratum. Ground traverses provided a subjective impression of the vegetation of the native woodland at the station and helped locate representative stands for intensive sampling.
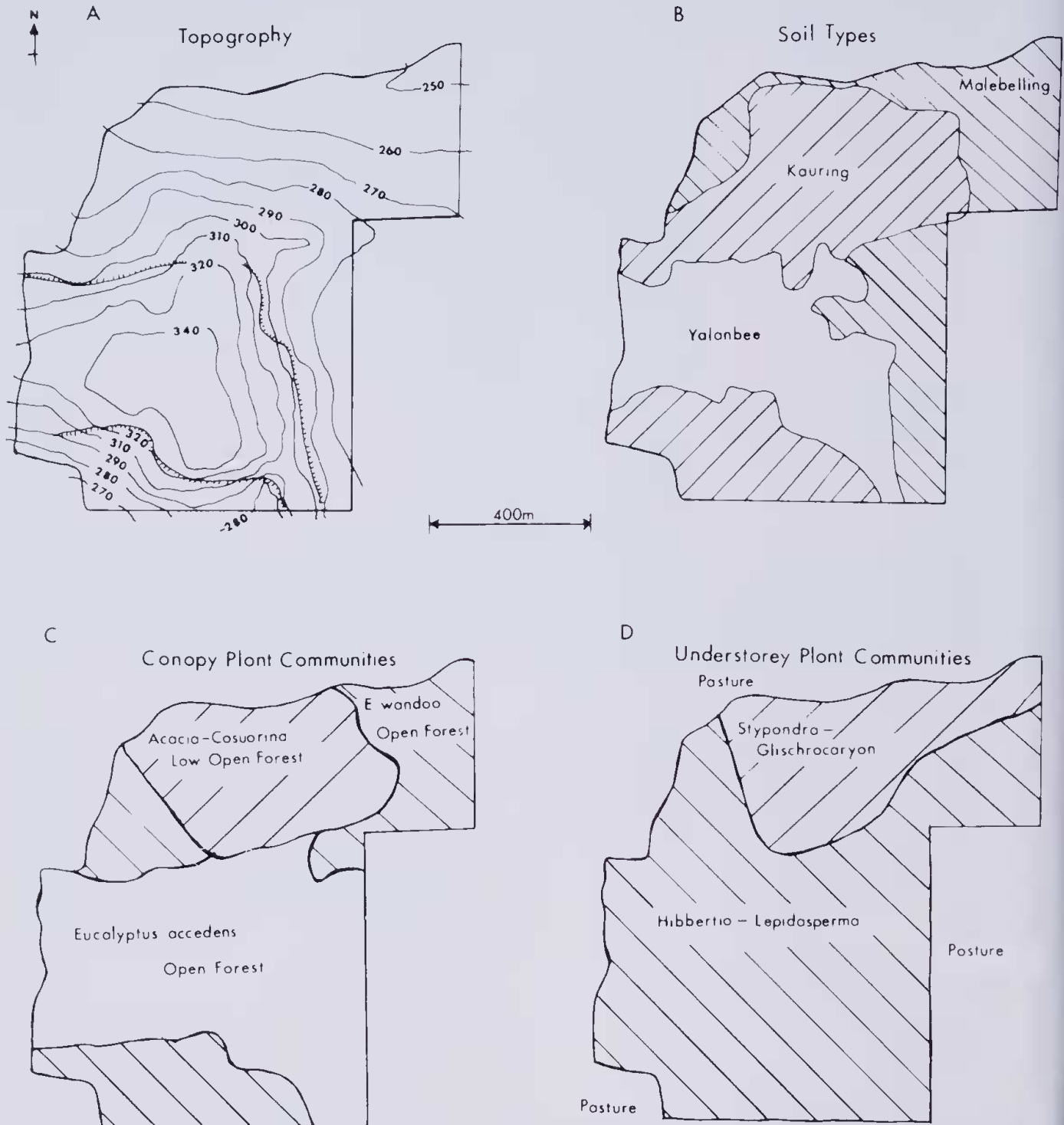
YALANBEE RESEARCH STATION NATURAL AREA

Figure 1.—Yalanbee Research Station Natural Area. (A) Topography shown by 5 m elevational contours. Breakaway slope margin is also shown. (B) Soil types of the study area after Dimmoch (unpublished data). (C) Canopy vegetational communities. (D) Understorey vegetation communities.

The tree stratum was sampled using 23 sites of 10 x 10 m. Within each site all trees (diameter at breast height (dbh) > 4 cm; height > 2 m) were identified to species and the dbh measured. A canopy density value for the site was obtained as the mean of four readings on a crown-cover densiometer (Lemmon 1956). The mean of the relative density and relative basal area provided species importance values for the primary stand by species data matrix.

The understorey stratum was sampled at 25 sites distributed throughout the natural woodland area. At each site a line transect of sixteen 1 m² quadrats provided an estimate of species cover and frequency. An understorey importance value for each species was calculated by summing the mean cover and frequency percentages and dividing by two. The vegetation data was subjected to several ordination techniques using the Ordiflex Program Package of Gauch (1973) and a polythetic agglomerative classi-fication system (Gilbert and Walls 1966) using per-centage similarity (Bray and Curtis 1957). Mapping divisions were constructed objectively from the results of the data analysis. By locating the sites on aerial photographs and using apparent photographic similarity, physiognomic features, geomorphological data and further field observation, the vegetation maps were developed. The canopy plant communities were named for the dominant species and the struc-tural classifications of Specht (1970). Understorey plant communities were named for their most important species, even though the two species were only a part of very diverse assemblages of species.

Canopy Communities

The three communities designated were 1) Powder-bark (*Eucalyptus accedens*) open forest, 2) Wandoo (*E. wandoo*) open forest, and 3) *Acacia-Casuarina* (*Acacia acuminata-Casuarina huegeliana*) low open forest (Fig. 1c). The Powderbark open forest was dominated by *E. accedens* and occurred on the old lateritic plateau and the eastern break-away slope. Other tree species in the community were *Dryandra sessilis*, *E. wandoo*, *E. marginata* and *E. calophylla*. *D. sessilis* and *E. marginata* were restricted to areas of the lateritic plateau. The average canopy cover of the community was 38% and the mean height of the trees was 42 m.

The Wandoo open forest community named for the dominant species, *E. wandoo*, was found in three areas of the native vegetation. These occurred on the southern steep break-away slopes, the north-eastern more gradual slopes and the nearly flat north-western corner region. Other occasional associates of *E. wandoo* in this community were *Acacia acuminata*, *E. calophylla*, *C. huegeliana* and *E. accedens*. Canopy cover averaged 46% and the mean height of the trees was 39 m.

The *Acacia-Casuarina* low open forest was co-dominated by *Acacia acuminata* and *Casuarina huegeliana*. The community was confined to the northern slopes and restricted to the soils which were shallow and overlying granitic parent material. Other tree species in the community were *E. accedens*, *E. calophylla* and *E. wandoo*. Mean canopy cover

was 33%, but the range of between 5% and nearly 100% gives a better representation of the discontinuous nature of the distribution of thickets of *Acacia* and *Casuarina*. Average tree height was 7 m.

Understorey Communities

Unlike the separation into three apparent communities found in the canopy, only two distinct types of understorey were delineated in the analysis of the data from the understorey vegetation sampling data. The extreme heterogeneity of the understorey vegetation presented difficulties and even the samples within the same major group have only limited similarity. The two very broad classification groups were designated as the *Hibbertia-Lepidosperma* community, and the *Stypandra-Glischrocaryon* community.

The *Hibbertia-Lepidosperma* community covered the majority of the area except the north-central region (Fig. 1d). *Hibbertia hypericoides*, *Lepidosperma tenue*, *L. scabrum*, and *Conostylis setigera* were common throughout the area (Table 1). *Hakea lissocarpa*, *Acacia celastrifolia*, *Calothamnus sanguineus*, *Adenanthos cygnorum* and *Gastrolobium trilobium* were dominants in restricted areas of the community. The understorey layer generally ranged from 0.5 m to 1.5 m in height. Percentage cover ranged from areas almost denuded of understorey species on the break-away slopes to 75% in areas on the lateritic plateau.

The *Stypandra-Glischrocaryon* community was restricted to soils of granitic origin within the areas of *Acacia-Casuarina* low open forest. *Stypandra imbricata* and *Glischrocaryon aureum* were common through this region (Table 1). Other common species were *Opercularia vaginata*, *Trymalium ledifolium*, *Scaevola fasciculata*, *Xanthorrhoea preissii* and *Neurachne alopecureoidea*. The shrub height rarely exceeded 1 m except for the occasional *X. preissii*. Presenting the data for the two under-storey communities as mean cover values and frequency percentages (Table 1) provides information on plants available to the grey kangaroo for food.

Kangaroo diet

Spot-lighting surveys reveal that grey kangaroo at the Yalanbee Experiment Station do feed in the pastoral areas adjacent to the native woodland (G. Arnold, unpublished data). These survey techniques cannot be used effectively, however, to observe the animals feeding in the heavy scrub of the native bushland areas. An important aspect of the current study was to discover what plants the grey kangaroo utilized in their diets and to determine if the diet changed markedly when the winter rains made green feed more readily available. As the population dynamics of the group were also under study, direct analysis of rumen contents of culled animals was not possible. Indirect methods using identification of faecal pellet plant fragments and records of grazed plant species provided the best alternatives.

Table 1

Mean percentage cover values and frequency percentages for species determined from the sites classified into the *Stypandra-Glischrocaryon* and *Hibbertia-Lepidosperma* communities. Abbreviations are: for Order. Monocotyledonae (M) and Dicotyledonae (D); and for Life Form, Shrub (S), and Herbaceous Perennial (H). All non-legume species found in less than 3% of quadrats grouped as "minor" species.

Species	Order	Family	Life Form	Stypandra-Glischrocaryon Cover	Stypandra-Glischrocaryon Freq.	Hibbertia-Lepidosperma Cover	Hibbertia-Lepidosperma Freq.
Stypandra imbricata	M	Liliaceae	S	3·20	47·5		
Glischrocaryon aurea	D	Haloragaceae	S	2·50	41·2	0·11	3·4
Scaevola fasciculata	D	Goodeniaceae	S	3·00	40·0		
Neurachne alopecuroides	M	Poaceae	H	1·10	57·5	0·57	20·0
Phyllanthus calycinus	D	Euphorbiaceae	S	0·60	31·4	0·56	13·8
Trymalium ledifolium	D	Rhamnaceae	S	6·40	31·3	0·47	4·0
Opercularia vaginata	D	Rubiaceae	H	2·30	25·0	0·31	4·7
Stackhousia pubescens	D	Stackhousiaceae	S	0·40	18·8		
Bossiaea eriocarpa	D	Papilionaceae	S	0·80	16·2	0·38	10·6
Anthocercis littorea	D	Solanaceae	S	1·30	11·2		
Lomandra caespitosa	M	Liliaceae	S	0·20	10·0	0·06	5·9
Acacia acuminata	D	Mimosaceae	S	0·38	3·8		
Gompholobium preissii	D	Papilionaceae	S	0·06	6·2	0·09	3·8
Xanthorrhoea preissii	M	Liliaceae	S	0·20	1·2	1·36	5·3
Lomandra hermaphrodita	M	Liliaceae	H	0·06	1·2	0·14	5·9
3 Minor Dicot spp.	D			0·06	...		
26 Minor Dicot spp.	D					2·75	
8 Minor Monocot spp.	M					0·28	
Adenanthos cygnorum	D	Proteaceae	S			0·69	3·0
Hakea ruscifolia	D	Proteaceae	S			0·48	3·1
Lepidosperma angustatum	M	Cyperaceae	H			0·11	3·4
Trymalium angustifolium	D	Rhamnaceae	S			0·56	3·6
Stylidium brunoneanum	D	Stylidiaceae	H			0·06	3·8
Baeckea camphorosmae	D	Myrtaceae	S			0·30	3·8
Hakea ambigua	D	Proteaceae	S			0·83	3·8
Dryandra sessilis	D	Proteaceae	S			0·54	3·8
Dryandra carduacea	D	Proteaceae	S			1·18	4·1
Acacia celastrifolia	D	Mimosaceae	S			0·72	4·7
Casuarina humilis	D	Casuarinaceae	S			0·83	4·7
Hakea incrassata	D	Proteaceae	S			0·55	5·0
Lasiopetalum molle	D	Sterculiaceae	S			0·13	5·3
Borya nitida	M	Liliaceae	S			0·78	5·3
Gastrolobium trilobium	D	Papilionaceae	S			2·02	5·6
Petrophile striata	D	Proteaceae	S			1·23	6·6
Hakea undulatum	D	Proteaceae	S			0·63	6·3
Lepidobolus sp.	M	Restionaceae	H			0·92	6·6
Leptospermum erubescens	D	Cyperaceae	H			0·85	6·9
Tetraria octandra	M	Cyperaceae	H			0·57	7·2
Calothamnus sanguineus	D	Myrtaceae	S			2·22	7·8
Dampiera lavandulacea	D	Goodeniaceae	S			0·19	8·4
Dryandra nivea	D	Proteaceae	S			1·04	8·7
Acacia pulchella	D	Mimosaceae	S			0·53	9·1
Melaleuca holosericea	D	Myrtaceae	S			2·53	9·7
Hakea trifurcata	D	Proteaceae	S			2·74	10·0
Calytrix brachyphylla	D	Myrtaceae	S			0·65	12·8
Lepidospermum tenue	M	Cyperaceae	H			0·63	14·7
Hibbertia montana	D	Dilleniaceae	S	0·25	3·8	0·78	15·9
Jacksonia restioides	D	Papilionaceae	S			1·42	15·6
Hemigenia canescens	D	Lamiaceae	S			1·16	15·6
Loxocarya flexuosa	M	Restionaceae	H	0·71	7·5	1·71	20·0
Hakea lissocarpha	D	Proteaceae	S			2·90	21·6
Lepidospermum scabrum	M	Cyperaceae	H	0·06	1·2	1·19	21·8
Conostylis setigera	M	Haemodoraceae	S	0·10	6·2	1·52	34·1
Hibbertia hypericoides	D	Dilleniaceae	S			5·72	48·1

The epidermis of leaves has a number of characteristics which are useful in the identification and classification of plant species. They also have the advantage that most of the cuticular and epidermal tissue remain undigested in the passage through the digestive systems of animals. Cuticular material can also be identified in animal stomach contents and faeces. (Stewart 1967, 1971, Stewart and Stewart 1970). No study of epidermal characteristics of species of the Wandoo Woodland, however, was available for identifying epidermal fragments in the faecal pellets of the grey kangaroo. An initial period was, therefore, necessary to prepare a series of reference slides of epidermal material from plants known from the woodland and pasture areas of the Yalanbee Experiment Station (Halford *et al.* 1984.)

Epidermis Reference Collection

Reference slides of suitable quality were produced of 60 of the 140 species identified in the native vegetation area and adjacent pasture using the techniques of Storr (1961) and Jain (1976). The relative merits of each of these techniques are discussed in a previous paper (Halford *et al.* 1984). In those species which have leaves or phyllodes which are reduced or absent, the epidermal features of stem material were used for descriptive purposes. Also in a few cases there was some difficulty in finding sufficient species-specific epidermal characters to differentiate members within one genera. There was, however, little difficulty in separating generic groups on the basis of epidermal characters alone.

Faecal Material Preparation

Microscopic observation of the untreated faecal material did not provide sufficient clarity of the epidermal fragments for identification. A modification of Storr's (1961) preparation was, therefore, used to clear epidermal material from residual fibre fragments. Such acid digestion procedures have presented problems in animal diet analyses previously (e.g. Griffths and Barker 1966) but it was felt that the ability to identify plant species in the faecal pellet was enhanced to a far greater extent than the potential to lose species from the dietary list due to complete digestion of soft epidermal tissue by this method. Each faecal pellet was split into two equal portions. One portion was stored to allow for possible re-analysis. The other portion was placed in a 20 ml solution of equal parts of 10% chromic acid and 10% nitric acid and gently boiled for 15 min. After maceration, the material was allowed to cool, rinsed with a very dilute solution of KOH. The material was then suspended in a 0.5% solution of gentian violet in 95% alcohol. After staining for 48 h, the material was passed through a 0.5 mm sieve and both the fractions resuspended. Samples of each were placed on microscope slides and mounted in euparal. The separation of these fractions generally assisted in the visual clarity of the slides. The slides were examined at a magnification of 70 x. All fragments lying in the field of view along fifteen transects of the length of the slide were examined, compared to the collection of reference preparations, and identified. In a series of observations on subsamples of pellets, it was determined that after five slides from the same pellet, very few new species were recognised. Subsequently, therefore, the list of species from a single pellet was determined from five subsample slides.

Field Collections

Faeces were collected in areas of the two understorey communities and from adjacent pastures where kangaroos were observed. Faecal samples were obtained on April 4 and May 15, 1979. Two additional sets of samples were collected from the two native vegetation areas on June 6 and June 25, 1979. On May 21st, 25 mm of rain fell at the Experimental Station. This rainfall was followed by another 15 mm in the six days to the end of the month. These rains provided the first effective growing period of the season and produced good growth of annuals in the pastures and areas around the granite outcrops of the *Stypandra-Glischrocaryon* community. Faecal samples were not collected on the last two dates from the pasture areas because of the thick regrowth of the pasture grasses. Only recently deposited faeces were collected during each sampling. This was achieved by noting that newly deposited material had a shiny mucus layer. The shiny appearance was lost within one week. Faecal pellets were collected by traversing the sites systematically. From each deposit of faeces, two pellets were taken for analysis. The remaining faeces were removed and kept separately to ensure that duplication of sampling did not occur. However, this collection method did not necessarily avoid sampling more than once from the same kangaroo.

The number of faecal pellets collected in the field samples ranged from 26 to 42 pellets. Samples returned from the field sites were oven-dried at 80°C for 24 h and stored at room temperature until analysis.

Field Grazing Observations

During the course of the study a list of plants which appeared to be grazed by the larger herbivores was compiled. These were easily distinguished from those grazed by insects but it was not possible to differentiate between the grazing of grey kangaroo, brush wallaby and rabbits, the only large herbivores in the area. There were 32 taxa of native plants observed to be grazed in the areas of native bush (Table 2). The herbaceous perennials and annuals which appeared after the rains were often heavily grazed, especially around the granite outcrops of the *Stypandra-Glischrocaryon* area.

Species Recorded from Faecal Pellets

Thirty-one species of native plants were recorded from grey-kangaroo faeces collected at Yalanbee (Fig. 2). The exotic grasses *Bromus rubens*, *B. rigidus*, *Avena sativa* and *Triticum* sp. constituted the group referred to as "pasture grasses". These grasses were not easily separated by their epidermal patterns and to avoid misidentification, no attempt was made to distinguish between the species in the faecal samples. Other plants of the pasture area, which included several species each of *Lupinus* and *Trifolium*, and *Arctotheca calendula*, were not found in the faecal collections. Of the natives, the most commonly identified species was *Conostylis setigera*, a tufted perennial monocotyledon, occurring in 60% of all pellets analysed during the survey. *Opercularia vaginata* and *Bossiaea eriocarpa* occurred in over 40% of pellets analysed. *Adenanthos cygnorum*, and two taxa which were difficult to separate, a *Hakea* sp. and *Casuarina* sp, were also frequently observed in the faecal samples. Of the species observed in the faeces, 29% were monocotyledons and the remaining 71% were dicotyledons. When compared to 22% monocotyledon—78% dicotyledon percentages for the field sample ratio, it appears the grey kangaroo show some favour for the monocotyledons but further study needs to be done to verify this possibility.

When the data from the summer collections from the different understorey communities were compared there were some notable differences, (Fig. 2). *Acacia celastrifolia*, a plant restricted to the *Hibbertia-Lepidosperma* community, was common in the samples from this area and absent from the *Stypandra-Glischrocaryon* region. *Acacia celastrifolia* was also found in faecal pellets collected in the pasture areas adjacent to the *Hibbertia-Lepidosperma* region. *Calothamnus sanguineus*, *Adenanthos cygnorum* and the grouping of the several *Hakea* species were identified from all the collection areas but were more frequent in the faecal samples from the *Hibbertia-Lepidosperma* zone and the pasture areas. The pasture grasses and *Conostylis setigera* were common in the faecal collections from all sites. *Opercularia vaginata* and *Bossiaea eriocarpa* were very common in the two native vegetation sites, but were less frequent in the samples from the pasture.

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Table 2

Species of the native woodland showing signs of grazing by large herbivores and confirmed in faecal pellet analyses. Asterisk (*) denotes those species grazed after the first effective rains. See Table 1 for abbreviations.

Species	Order	Family	Life form	Grazed	Faeces
Acacia celastrifolia	D	Leguminosae	S	....	X
Adenanthos cygnorum	D	Proteaceae	S	X	X
Anthocercis littorea	D	Solanaceae	S	X	
Bossiaea eriocarpa	D	Leguminosae	S	X	X
Burchardia multiflora*	M	Liliaceae	H	X	
Calothamnus sanguineus	D	Myrtaceae	S	X	X
Casuarina spp.	D	Casuarinaceae	S	....	X
Conostylis setigera	M	Haemodoraceae	H	X	X
Dampiera lavandulacea	D	Goodeniaceae	S	X	X
Daviesia juncea	D	Leguminosae	S	X	X
Daviesea decurrens	D	Leguminosae	S		X
Dianella revoluta*	M	Liliaceae	H	X	..
Dichopogon sp.*	M	Liliaceae	H	X	
Drosera spp.*	D	Droseraceae	H	X	
Dryandra carduacea	D	Proteaceae	S	X	X
Gastrolobium trilobium	D	Leguminosae	S	X	X
Gastrolobium calycinum	D	Leguminosae	S	X	X
Glischrocaryon aureum	D	Haloragaceae	S	X	X
Gompholobium preissii	D	Leguminosae	S	....	X
Gyrostemon subnudus	D	Phytolacaceae	S	X	..
Hakea ambigua	D	Proteaceae	S		X
Hakea trifurcata	D	Proteaceae	S	X	X
Hakea undulata	D	Proteaceae	S		X
Jacksonia restioides	D	Leguminosae	S	X	X
Lasiopetalum molle	D	Steruliaceae	S	X	
Lepidosperma scabrum	M	Cyperaceae	H	X	X
Lomandra effusa	M	Liliaceae	H	X	X
Lomandra hermaphrodita	M	Liliaceae	H	X	X
Loxocarya flexuosa	M	Restionaceae	H		X
Mirbelia ramulosa	D	Leguminosae	S	X	X
Neurachne alopecuroidea* ...	M	Poaceae	H	X	X
Native grasses (not flowering)*	M	Poaceae	H	X	
Opercularia vaginata	D	Rubiaceae	H	X	..
Petrophile serruriae	D	Proteaceae	S	X	
Stylidium affine	D	Stylideaceae	H	X	....
Stypandra imbricata	M	Liliaceae	H	X	X
Tetraria octandra	M	Cyperaceae	H	X	
Tetratheca confertifolia	D	Tremandraceae	S	X	
Tribonanthes uniflora	M	Haemodoraceae	H	X	
Xanthorrhoea preissii	M	Liliaceae	S	....	X

Change in the frequency of plant species present in the faeces following the onset of winter rains were apparent, despite the relatively small sample (Fig. 3). The percentage of pellets containing pasture grasses was higher following the initial winter rains and the consequently greater availability of the pasture grasses. *Conostylis setigera* remained a common constituent in the diet both before and after the beginning of the winter growing season. The frequency of occurrence of *Opercularia vaginata*, *Bossiaea eriocarpa* and *Casuarina* spp. decreased in the winter samples when compared to the pre-rainfall collections. *Gompholobium preissii* and *Phyllanthus calycinus* were only recorded in faecal samples collected during winter. Also, there was a drop from 24 taxa in the pellets sampled from collections before the rains, to 13 in the samples following the first rains.

Diet Preferences

Information on diet preference can be developed when the field frequency of a plant species in the native communities is compared to the frequency of occurrence in the samples of the diet. An index of diet preference was calculated using the frequency percentage of a species from all native understorey field samples combined divided by the frequency of occurrence of the species from all faecal pellets analysed. The resulting data was then somewhat subjectively classified into species which were 1) highly preferred, ratio > 3.00; 2) moderately preferred, ratio 2.00-3.00; 3) of low preference, ratio 1.00-2.00; and 4) of rare occurrence in diet, ratio < 1.00. It is apparent that the pasture grasses are an important component in the diet of the grey kangaroo at the Yalanbee Experimental Station, even though the animals must leave their resting areas to graze (Table 3). Of the native species, *Adenanthos cygnorum*, *Casuarina* spp. and *Opercularia vaginata* received the highest diet preference ratios. Other preferred native species were *Acacia celastrifolia*, *Hakea* spp., *Gastrolobium trilobium*, *Bossiaea eriocarpa* and *Calothamnus sanguineus*. *Conostylis setigera* was the most frequently encountered species in the faecal pellets. Its frequent field presence resulted in a rating subjectively placing it with moderately preferred species.
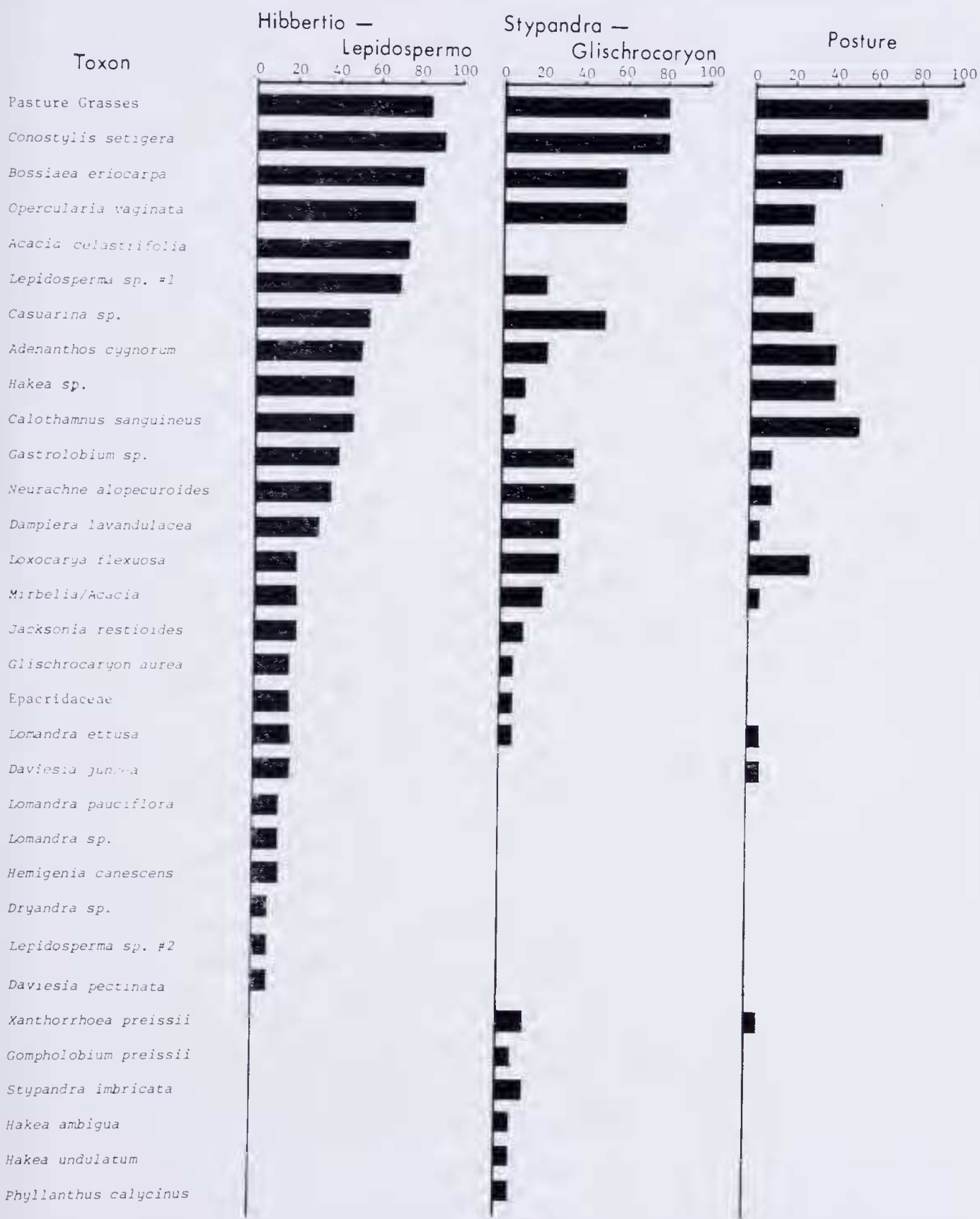
Figure 2.—Collection site variation in the diet of the grey kangaroo. Frequency of occurrence of plant species in faecal pellets collected in sites of pasture, the *Hibbertia-Lepidosperma* understorey community and the *Stypandra-Glischrocaryon* under-standard surveyor's measure.
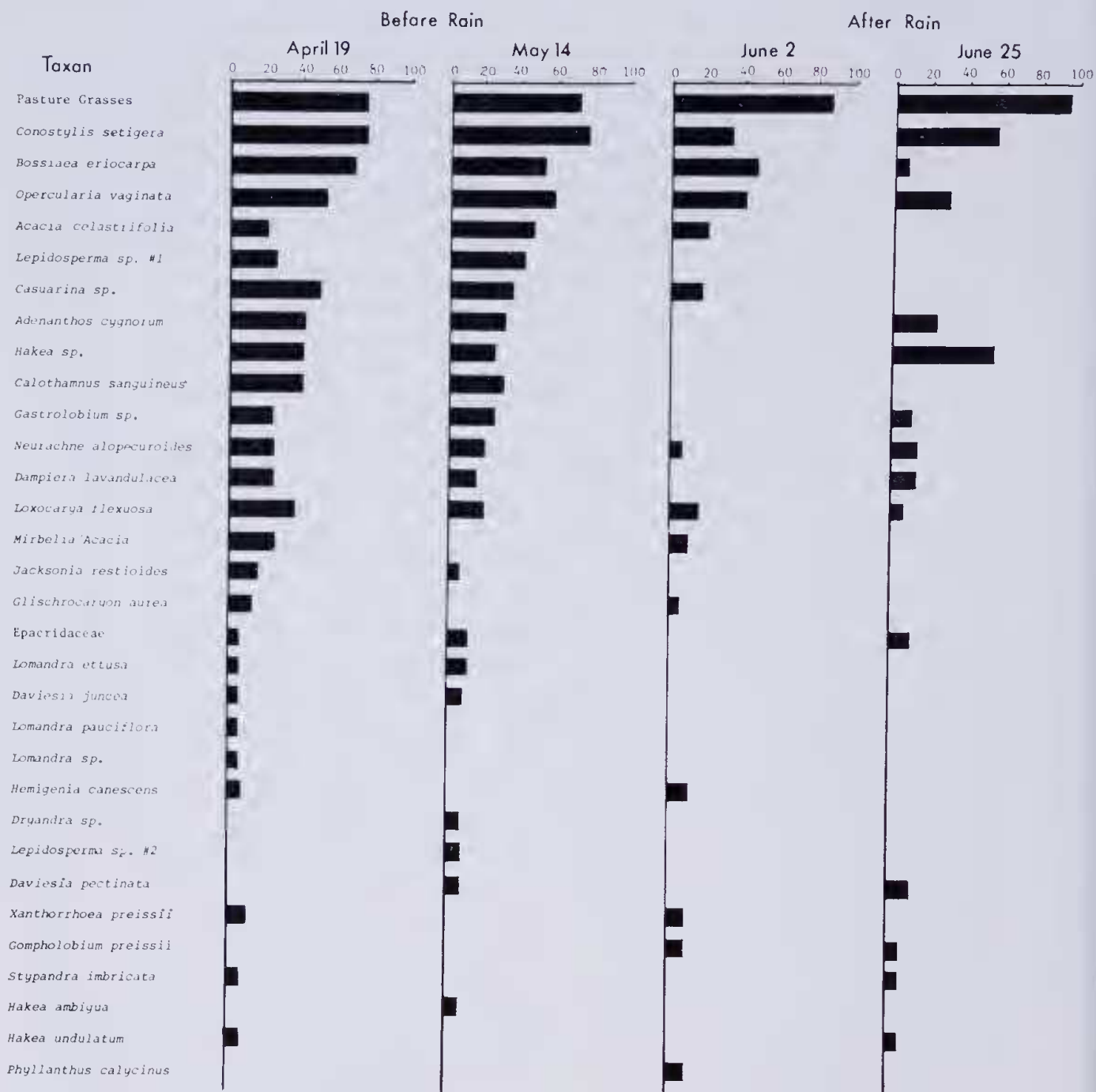
Figure 3.—Diet constituents of the grey kangaroo. Frequency of occurrence in faecal pellets collected on April 19 and May 14, 1979 before significant rainfall, and June 2 and June 25 during the period of good vegetational condition. Data from all collection sites were grouped.

Discussion

Grey kangaroos, like most large herbivores, consume a broad spectrum of plant species representing a range of plant life forms. The grey kangaroo in the native woodland-pasture landscape of the Yalanbee Experimental Station are consuming a mixture of native species in addition to the grasses of the pasture areas. A large number of native dicotyledons occur in the diet of the grey kangaroo in this study. Previous studies of the food habits of large macropods show they are predominantly grazers, with grasses the most important part of the diet. The eastern grey kangaroo was observed by Kirkpatrick (1965) to graze on native grasses and introduced pasture grasses in southern Queensland. Griffiths and Barker (1966) and Griffiths *et al.* (1974) also observed that most of the grazing of the eastern grey kangaroo was confined to the pasture grasses and that dicotyledons represented only a very small part of the diet. These studies, however, were carried out in open grasslands where the dicotyledons are only minor components.

Table 3

Diet preferences of western grey kangaroo at the Yalanbee Experimental Station determined as a ratio of the diet frequence and the field frequency. For diet preference categories, see text.

Species	Diet Frequency	Field Frequency	Preference Ratio	Diet Preference
Pasture Grasses	82·5	0·0	∞	High
Adenanthos cygnorum	28·2	2·4	11·8	High
Casuarina spp.*	27·5	3·8	7·2	High
Opercularia vaginata	43·8	6·2	7·1	High
Acacia celastrifolia	22·5	3·8	5·9	High
Hakea spp.*	32·5	7·8	4·2	High
Gastrolobium trilobium	18·8	4·5	4·1	High
Bossiaea eriocarpa	46·2	11·8	3·9	High
Calothamnus sanguineus	21·2	6·2	3·4	High
Daviesia juncea	3·8	1·5	2·5	Moderate
Dampiera lavandulacea	16·2	6·7	2·4	Moderate
Conostylis setigera	60·2	28·8	2·1	Moderate
Epacridaceae*	6·2	3·0	2·0	Moderate
Lepidosperma spp.*	18·8	11·7	1·6	Low
Daviesia decurrens	2·5	1·6	1·5	Low
Mirbelia/Acacia	10·0	8·0	1·2	Low
Loxocarya flexuosa	21·2	17·5	1·2	Low
Xanthorrhoea preissii	5·0	4·5	1·1	Low
Gompholobium preissii	3·8	4·3	0·9	Rare
Jacksonia restioides	7·5	12·5	0·6	Rare
Glischrocaryon aureum	6·2	11·0	0·6	Rare
Dryandra spp.*	12·5	4·4	0·6	Rare
Hakea undulatna	2·5	5·0	0·5	Rare
Lomandra spp.*	3·0	6·7	0·4	Rare
Hakea ambigua	1·2	3·0	0·4	Rare
Hemigenia canescens	3·8	12·5	0·3	Rare
Stypandra imbricata	2·5	9·5	0·3	Rare
Phyllanthus calycinus	2·5	17·3	0·1	Rare

* Field frequencies of several species combined.

Studies on the yellow-footed rock wallaby in western New South Wales in rock outcrop areas, however, revealed that the dicotyledonous species were the dominant group in the diet of these animals (Dawson and Ellis 1979). In good vegetational conditions the largest component of the diet was composed of the small herbaceous ephemeral forbs. During drought conditions, the monocotyledons became a more important dietary component.

In our study, the proportion of monocotyledons to dicotyledons in the diet was nearly equal to the proportions in the habitat, although the preferences here also seem to make the monocotyledons slightly more favoured in the diets than in field sample values. It is apparent, however, that the western grey kangaroo in the Yalambee region is more of a browser than its eastern counterparts because a large percentage of the shrubby dicotyledons are included as dietary constituents.

Notable among the dicotyledons consumed were the legumes, *Bossiaea eriocarpa*, *Acacia celastrifolia*, *Gastrolobium* sp., *Mirbelia/Acacia*, *Jacksonia restioides*, *Daviesia juncea*, and *Gompholobium preissii*. *Casuarina* sp., also a species known to have symbiotic nitrogen fixation capacity, was also common in the dietary components. Although the nitrogen levels of the leaves of these taxa were not analyzed in this study, the hypothesis that the kangaroo may be showing a preference to these species because of the added nitrogen content is a strong possibility. Other constitutents of actively growing plants such as Ca, P, K and moisture may also influence kangaroo preference.

Also notable, although not major components of the diet, were *Gastrolobium* spp., *Stypandra imbricata* and *Glischrocaryon aureum*, three species known to poison domestic stock (Gardner and Bennett 1956). The western grey kangaroo and other native mammals from the south-west of Western Australia have the ability to detoxify the secondary plant compounds found in species of *Gastrolobium* and *Oxylobium* (Oliver *et al.* 1977). It would not be surprising, therefore, to discover the western grey kangaroos also have the ability to tolerate the toxins produced by *Stypandra imbricata* and *Glischrocaryon aureum*.

The diet of the western grey kangaroo at the Yalanbee Experimental Station had a seasonality related to the greater availability of the pasture grasses following the first winter rains. The pasture grasses, however, were still an important constituent of the diet during the drought period of summer when the amount of edible material on the pasture areas was limited. Although annual species showed signs of grazing in the granite outcrop areas, no fragments of these ephemerals appeared in the faecal sample preparations. This may be because the annuals are only a minor component in the diet and the sampling procedure was not extensive enough to detect these species, or that fragments of these herbaceous species did not survive the digestive system of the kangaroo or the process of preparation of the faeces for analysis.

Although the determination of the reasons for the seasonal change in diet was beyond the scope of the current study, the seasonal switch to a preponderance of pasture plants and other ephemerals may be due to their greater nutritional quality. Storr (1964) observed seasonal fluctuations in the quality of the forage available to the Quokka *(Setonix brachyurus* Quoy and Gaimard) on Rottnest Island with respect to nitrogen. During summer and autumn there was a lower level of nitrogen available in grasses and shrubs compared to winter, when these plants would be actively growing. Ealey and Main (1967) observed that rainfall induced new seasonal growth which was high in nitrogen content.

An interesting point also is why the kangraoo still consumes a relatively large amount of the hard, sclerophyllous vegetation when there appears to be other, seemingly more edible, plant material available. This could be that abrupt changes in diet may have severe effects on the micro-fauna of the pseudo-rumen digestive system (Hume 1978) and the continued consumption of native sclerophylls is for roughage to balance the large quantity of soft ephemerals consumed after the onset of the rainy season.

There was little difference in species composition of the faeces from different sites. Also, there were pasture grasses in the faeces from both native vegetation sites as well as in faeces from the pasture areas. It is apparent that considerable movement of the animals takes place. This is also emphasized by the presence of *Opercularia vaginata* in faecal collections from all areas, despite being nearly restricted to the granite outcrop areas of the north

True quantification of the diet of the grey kangaroo at Yalanbee Experimental Station will require a greater understanding of the effects the kangaroo digestive system has on the plant epidermal tissue. Crocker (1959) emphasises that although survival of the leaf cuticle in the faeces of sheep was related to cuticle thickness, some of the diagnostic characters of the thinnest cuticles were completely obliterated during digestion. Slater and Jones (1971) showed that clover fed to sheep may be undetectable in the faeces. Storr (1961) in his studies of diet of the Quokka found there was a good correlation between the relative portions of native perennial plants fed under confinement conditions and the portions of their relative cuticular area in the faeces, but had difficulty in assessing the effect of the kangaroo digestive system when annual vegetation was used because the epidermis of the annual plants did not survive the preparation technique of boiling acid. Although Prince (1976) provided some information on the digestive efficiency of the western grey kangaroo, further studies are necessary to assess the ability of this species to digest cuticular plant material.

The study reported here using faecal analyses has shown that the western grey kangaroo at the Experiment Station still consume considerable numbers of native species, even though presented with extensive areas of surrounding pasture. Further data will be required before a management programme for the numbers of kangaroo in the population can be contemplated.

References

Bray, J. R. and Curtin, C. T. 1957).—An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.*, 27: 325-349.

Calaby, J. H. (1971).—The current status of Australian Macropodidae. *Aust. Zool.*, 16: 17-31.

Crocker, B. H. (1959).—A method of estimating the botanical composition of the diet of sheep. *N.Z.J. Agric. Res.*, 2: 72-85.

Dale, M. B. and Williams, W. T. (1978).—New method of species reduction for ecological data. *Aust. J. Ecol.*, 3: 1-5.

Dawson, T. J. and Ellis, B. A. (1979).—Comparison of the diets of yellow-footed Rock Wallabies and sympatric herbivores in western New South Wales. *Aust. Wildl. Res.*, 6: 245-254.

Ealey, E. H. M. and Main, A. R. (1967).—Ecology of the euro, *Macropus robustus* (Gould) in north-western Australia. III. Seasonal changes in nutrition. *CSIRO Wildl. Res.*, 12: 53-65.

Frith, H. J. (1964).—Mobility of the red kangaroo *Megaleia rufa. CSIRO Wildl. Res.*, 9:1-19.

Gardner, C. A. (1942).—The vegetation of Western Australia with special reference to the climate and soils. *J. Roy. Soc. W.A.*, 28: 11-87.

Gardner, C. A. and Bennetts, H. W. (1956).—The toxic plants of Western Australia. W.A. Newspapers Ltd., Perth.

Gilbert, N. and Wells, T. C. E. (1966).—Analysis of quadrat data. *J. Ecol.*, 54: 675-685.

Gauch, H. G. jr. (1973).—The Cornell Ecological Program Series. *Bull. Ecol. Soc. Amer.*, 54: 10-11.

Griffiths, M. and Barker, R. (1966).—The plants eaten by sheep and by kangaroos grazing together in a paddock in south-western Queensland. *CSIRO Wildl. Res.*, 11: 145-167.

Griffiths, M., Barker, R. and MacLean, L. (1974).—Further observations on the plants eaten by kangaroos and sheep grazing together in a paddock in south-western Queensland. *Aust. Wildl. Res.*, 1: 27-43.

Halford, D. A., Bell, D. T. and Loneragan, W. A. (1984).—Epidermal characteristics of some wandoo woodland species for studies of herbivore diets. *J. Roy. Soc. W.A.* Vol. 66: 111-118.

Hume, I. D. (1978).—Evolution of the macropodidae digestive system. *Aust. Mammol.*, 2: 37-41.

Jain, K. K. (1976).—Hydrogen peroxide and acetic acid for preparing epidermal peels from conifer leaves. *Stain Tech.*, 51: 202-204.

Kirkpatrick, T. H. (1965).—Food preferences of the grey kangaroo (*Macropus major* Shaw). *Qld. J. Agric. Anim. Sci.*, 22: 89-93.

Lemmon, P. E. (1956).—A spherical densiometer for estimating forest overstorey density. *For. Sci.*, 2: 314-320.

Main, A. R. (1968).—Psysiology in the management of kangaroos and wallabies. *Proc. Ecol. Soc. Aust.*, 3: 96-105.

Newsome, A. E. (1965).—The abundance of red kangaroos, *Megaleia rufa* (Desmarest) in central Australia. *Aust. J. Zool.*, 13: 269-287.

Oliver, A. J., King, D. R. and Mead, R. J. (1977).—The evolution of resistance to fluoroacetate intoxication in mammals. *Search*, 8: 130-132.

Prince, R. I. T. (1976).—Comparative studies of aspects of nutritional and related physiology of macropod marsupials. Unpublished Ph.D. thesis, University of W.A.

Slater, J. and Jones, R. J. (1971).—Estimation of the diets selected by grazing animals from microscopic analysis of the faeces—A warning. *J. Aust. Inst. Agric. Sci.*, 37: 238-239.

Specht, R. L. (1970).—Vegetation. Pages 42-67. *In* Leeper, G. W. The Australian Environment. (4th Ed.). CSIRO and Melbourne University Press.

Stewart, D. R. M. (1967).—Analysis of plant epidermis in faeces. A technique for studying the food preference of grazing herbivores. *J. Appl. Ecol.*, 4: 83-111.

Stewart, D. R. M. (1971).—Survival during digestion of epidermis from plants eaten by ungulates. *Rev. Zool. Bot. Afr.*, 82: 3-4.

Stewart, D. R. M. and Stewart, J. (1970).—Food preference data by faecal analysis for African plains ungulates. *Zool. Afr.*, 15: 115-129.

Storr, G. M. (1961).—Microscopic analysis of faeces, a technique for ascertaining the diet of herbivorous mammals. *Aust. J. Biol. Sci.*, 14: 157-164.

Storr, G. M. (1964).—Studies on marsupial nutrition. IV. Diet of the Quokka, *Setonix brachyurus* (Quoy and Gaimard) on Rottnest Island, Western Australia. *Aust. J. Biol. Sci.*, 17: 469-481.

Disturbed Rb-Sr systems of the Archaean Duffer Formation, Eastern Pilbara Block, Western Australia

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Abstract

The Duffer Formation is a thick sequence of Archaean calc-alkaline felsic volcanics in the Pilbara Block. A zircon U-Pb age of 3 453 ± 16 Ma has recently been obtained from this unit (Pidgeon 1978a). However, most Duffer Formation volcanics have been altered and their Rb-Sr whole-rock systems disturbed, indicating ages of between 3 000 and 3 100 Ma. It is likely that a metamorphic event resulted in local isotopic homogenization of Sr at this time.

In this study detailed sampling and description of typical units within the Duffer Formation was carried out to enable the recognition of the least altered lithologies. Samples from McPhee Creek do not define a single isochron but seven samples give an age of 3 018 ± 75 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.701 5 ± 0.000 7, whereas samples from Spinaway Creek define an isochron of age 3 063 ± 114 Ma and initial ratio 0.703 0 ± 0.000 7. However five "least altered" volcanics from McPhee Creek gives an age of 3 471 ± 125 Ma and an initial ratio of 0.699 8 ± 0.000 9. This initial ratio indicates that Duffer Formation magmas were derived from a source with a mantle-like Sr isotopic composition.

Introduction

The origin of early Archaean felsic volcanics is of primary importance to the understanding of Archaean crustal evolution. In many areas of modern felsic igneous activity Rb-Sr trace element and isotopic data provide useful petrogenetic evidence. Unfortunately the mobility of Rb and Sr during hydrous alteration and low grade metamorphism frustrates the interpretation of data from many Precambrian volcanic terrains (e.g. Allsopp et al. 1968, Page 1978). This paper presents Rb-Sr whole-rock data obtained during a study of the Duffer Formation, an early Archaean sequence of calc-akaline felsic volcanics in the eastern Pilbara Block (Barley 1980, 1981a).

Recently a zircon U-Pb age of 3 453 ± 16 Ma (Pidgeon 1978a) and galena Pb model ages of between 3 400 and 3 500 Ma (Sangster and Brook 1977, Richards et al. 1981) have been obtained from units within the Duffer Formation. However, previous Rb-Sr whole-rock isotopic studies (Pidgeon 1978a, Jahn et al. 1981) indicate that post-magmatic alteration processes have involved widespread mobility of Rb and Sr and disturbance of Rb-Sr whole-rock systems. This is reflected by considerable scatter on isochron diagrams (plots of $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$), and regression analyses which indicate ages which are younger than those obtained from zircon and galena studies. Such "isochrons" possess anomalous initial $^{87}Sr/^{86}Sr$ ratios which are of little use in petrogenetic interpretations.

In this study, detailed description and sampling of typical units within the Duffer Formation was carried out to enable the recognition of the least altered lithologies. Analyses of several samples of least altered lithologies within individual units, when compared with analyses of altered lithologies from the same unit, provide an indication of the mobility of Rb and Sr during alteration and the effect this has on Rb-Sr whole-rock systems. The zircon U-Pb age obtained by Pidgeon (1978a) is used as a reference in evaluation of the Rb-Sr whole-rock data.

Area of study

The Pilbara Block is the smaller of the two Archaean crustal blocks in Western Australia. It contains about 56 000 km² of granitoid-greenstone terrain, in which metamorphosed volcanic and sedimentary sequences (greenstones) form synclinoria and domes which are separated by large ovoid or elongate batholiths of granitoid and gneiss (Fig 1).

In the eastern Pilbara Block the greenstone sequence is divided into the lower, dominantly volcanic, Warrawoona Group and the overlying sedimentary rocks of the Gorge Creek Group (Hickman 1981). The Warrawoona Group consists of sequences of mafic volcanics interlayered with cherty sediments and sequences of felsic volcanics. The Duffer Formation is a distinctive unit within the Warrawoona Group, composed dominantly of andesite and dacite. It is best developed in the Marble

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Bar Belt, the McPhee Dome and the Kelly Belt (Fig. 1). Studies of the Duffer Formation in the McPhee Dome and the Kelly Belt (Barley 1980, 1981a) indicate that it forms part of a calc-alkaline volcanic association. To the west of the Corunna Downs Batholith (Fig. 1) the Duffer Formation has been dated at 3 453 ± 16 Ma by zircon U-Pb techniques (Pidgeon 1978a). Similar galena Pb model ages of between 3 400 and 3 500 Ma (Sangster and Brook 1977, Richards *et al.* 1981) for the Big Stubby and Lennons Find volcanogenic Zn-Pb

sulphide deposits (Fig. 1) support the view that the zircon age is a reliable age of formation.

Metamorphism of the greenstone sequence ranges from prehnite-pumpellyite to amphibolite facies and has been accompanied by varying degrees of strain. Recrystallization of greenstones during low grade metamorphism has resulted in extensive redistribution of many elements and in the formation of mesoscopic zones of alteration or metadomains rich in secondary mineral phases (Barley 1980). Alteration involved
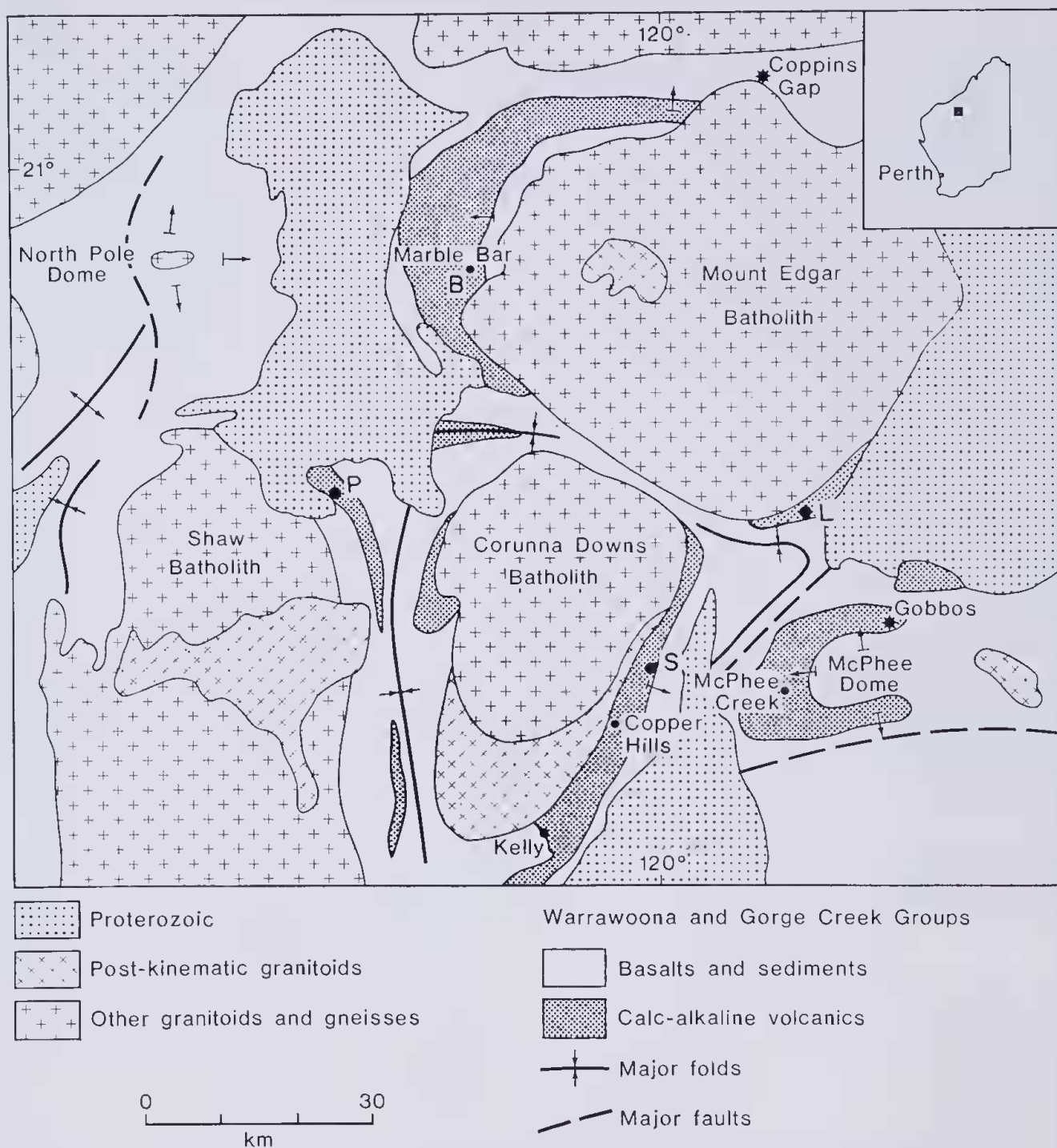

Figure 1.— Geological map of part of the eastern Pilbara Block (after Hickman, 1975, Hickman and Lipple 1975) showing the locations and sample sites referred to in this paper. S = Spinaway Creek, B = Big Stubby, L = Lennons Find, P = Site of U-Pb in zircon study (Pidgeon 1978a). The calc-alkaline volcanic unit includes both the Duffer and Wyman Formations of Lipple (1975).

hydrothermal fluids and is strongest in porous rocks such as pyroclastic units and adjacent to fractures or veins. The centres of massive lava flows and some very large (>30 cm) fragments in pyroclastic units are commonly relatively unaltered, and in areas which have experienced only prehnite-pumpellyite or lower greenschist facies metamorphism may contain relict igneous mineral phases. The style of alteration is also related to the composition of parent rocks. Basaltic and andesitic rocks typically developed metadomains rich in Ca-Al silicate (epidote or pumpellyite depending on metamorphic grade), albite or chlorite and carbonate. On the other hand, Ca-Al silicate metadomains are relatively uncommon in rocks of dacitic and rhyolitic composition where more diffuse albite, sericite and sericite-carbonate alteration is prevalent. Heterogeneous alteration of this type is common in sequences of low grade metavolcanics (Smith 1968, Jolly 1980) and is thought to have occurred during burial. In the eastern Pilbara metadomains can be recognized in greenstones which have subsequently been deformed and metamorphosed to medium or high metamorphic grade (Barley 1981b).

Analytical methods

Depending on grain size, between 0.5 and 1.5 kg of each sample was crushed and approximately 200 g reduced to —200 mesh using a tungsten carbide mill. The experimental procedure for Rb-Sr analysis used in this laboratory are described by Lewis *et al.* (1975) and de Laeter and Abercrombie (1970). The value of $^{87}Sr/^{86}Sr$ for the NBS 987 standard measured during this study was $0.710\,2 \pm 0.000\,1$, normalized to a $^{88}Sr/^{86}Sr$ value of 8.375 2. The value of 1.42×10^{-11} yr⁻1 was used for the decay constant of ^{87}Rb. Rb-Sr data are given in Tables 1 and 2. All errors are at the 95 per cent (2σ) confidence limits. Regression analyses of the data were carried out using the program of McIntyre *et al.* (1966).

Table 1

Average Rb and Sr concentrations of least altered volcanics McPhee Dome and Kelly Belt.

	Mafic volcanics (Salgash Subgroup)	Felsic volcanics (Duffer Formation)
No. of samples	37	21
Mean Rb (ppm)	8	32
Range of Rb values (ppm)	1 to 35	4 to 73
Mean Sr (ppm)	113	301
Range of Sr values (ppm)	25 to 340	140 to 563
Average Rb/Sr ratio	0·06	0·11

A method of sampling altered volcanic sequences developed by R. E. Smith and co-workers (Smith 1968, Jolly 1980), which allows evaluation of element movement during alteration has been used in this study. Alteration patterns in individual units were determined in the field and samples of each type of metadomain were taken, examined in thin section and classified on the basis of their secondary mineralogy (c.f. following discussion and Table 2).

As no samples which completely retained their original igneous mineralogy were found the following criteria (based on the examination of over 200 thin sections) were used when selecting samples of least altered metadomains for analysis:

1) that recognizable igneous textures are well preserved,

2) that secondary mineral phases are restricted to recognizable pseudomorphs after igneous minerals and that secondary mineral assemblages represent the approximate chemical composition of the igneous minerals replaced,

3) that samples contain no monomineralic aggregates of secondary minerals (e.g. epidote metadomains) and were collected as far as possible from inhomogeneities in outcrop, and

4) that samples contain no veins or cavities (e.g. amygdales) and contain less than 2% carbonate (visual estimate).

Where several samples classified as least altered metadomains from a single unit have been analysed, they show little variation in major and trace element contents. The assumption that the concentrations of most elements in least altered metadomains approximate original igneous compositions is also supported by smooth and generally tightly clustered trends on variation diagrams which are consistant with observed petrographic trends (Barley 1980).

For the purpose of this study the Duffer Formation was sampled at McPhee Creek in the McPhee Dome and at Spinaway Creek in the Kelly Belt (Fig. 1). Precise sample locations, descriptions of individual samples and major and trace element analyses are presented by Barley (1980).

Most of the McPhee Creek samples were taken from an outcrop of massive dacite. This unit is grey with diffuse patches (up to 20 cm in diameter) of pink, yellow and dark green coloured metadacite.

The grey metadomains are apparently least altered and show excellent preservation of igneous tectures with phenocrysts of plagioclase (some relict andesine-oligoclase) actinolite (replacing original pyroxene) and rare embayed quartz in a felted groundmass now composed of albite and epidote with minor chlorite and opaque oxides. Samples 86408, 86412 and 86426 are from grey least altered metadomains.

The contacts between grey and pink metadomains are generally quite diffuse (over 2 to 5 cm) and large areas of outcrop have a mottled grey and pink appearance. Pink metadomains contain abundant albite, sericite and carbonate, often partially retaining the textures and mineral assemblages evident in grey metadomains. Abundant carbonate (up to 10%) gives the pink metadomains their distinctive colour. Pink metadomains are enriched in Si, Al, K, Na and Rb relative to grey metadomains and are generally depleted in most other elements. Samples 86418 and 86419 are from pink albite and sericite-rich metadomains.

Yellow metadomains are more sharply defined with mineralogy and texture changing within less than a centimetre. The yellow metadomains are characterized by saccharoidal aggregates of epidote with minor quartz and carbonate. Original igneous

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Table 2

Rb-Sr analytical data for Duffer Formation samples

(i) *McPhee Creek*

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	Sample Type
86424	13	340	0·040 ± 0·001	0·115 ± 0·002	0·70721 ± 0·00051	dacite, yellow metadomain
86435	17	230	0·070 ± 0·002	0·202 ± 0·005	0·71025 ± 0·00012	basalt, least altered metadomain
86412	14	183	0·084 ± 0·001	0·243 ± 0·003	0·71181 ± 0·00009	dacite, least altered metadomain
86408	35	330	0·104 ± 0·002	0·300 ± 0·006	0·71479 ± 0·00022	dacite, least altered metadomain
86409	43	240	0·185 ± 0·003	0·535 ± 0·008	0·72531 ± 0·00025	dacite, yellow metadomain
86426	73	300	0·244 ± 0·004	0·706 ± 0·009	0·73506 ± 0·00018	dacite, least altered metadomain
86413	48	147	0·331 ± 0·003	0·960 ± 0·01	0·74849 ± 0·00019	andesite, least altered metadomain
86419	125	290	0·435 ± 0·008	1·26 ± 0·01	0·75658 ± 0·00031	dacite, pink metadomain
86418	125	280	0·445 ± 0·008	1·29 ± 0·01	0·75815 ± 0·00033	dacite, pink metadomain

(ii) *Spinaway Creek*

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	Sample Type
86456	1·4	195	0·007 ± 0·0002	0·020 ± 0·0005	0·70378 ± 0·00015	basalt, least altered metadomain
86400	35	515	0·067 ± 0·0008	0·194 ± 0·0002	0·71182 ± 0·00019	dacite, least altered metadomain
86363	27	320	0·083 ± 0·001	0·240 ± 0·003	0·71398 ± 0·00016	dacite, least altered metadomain
86402	53	295	0·180 ± 0·002	0·521 ± 0·006	0·72609 ± 0·00021	dacite, least altered metadomain
86405	63	340	0·184 ± 0·002	0·532 ± 0·006	0·72628 ± 0·00025	dacite, least altered metadomain
86407	68	290	0·236 ± 0·003	0·684 ± 0·008	0·73375 ± 0·00022	dacite, least altered metadomain

NOTE: The Rb and Sr concentrations and Rb/Sr ratios have been determined by X-ray Fluorescence Spectrometry. We believe that the values are accurate to ± 5%. The Rb/Sr values do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values listed.

textures are often completely destroyed. Small white patches (1 cm) within metadomains are rich in prehnite. Yellow metadomains are strongly enriched in Ca and depleted in most other elements with the exception of Al and Fe. Samples 86409 and 86424 are from grey metadomains which contain small (up to 2 cm) irregular yellow epidote-rich metadomains.

Sample 86413 is a grey metadomain from an outcrop of massive andesite and sample 86435 a relatively unaltered basalt from the Duffer Formation in McPhee Creek.

The Spinaway Creek samples were taken from the largest fragments (30-50 cm in diameter) in a subaqueous pyroclastic unit (described in Barley *et al.* 1979). With the exception of sample 86456 which is a least altered basalt from a unit overlying the Duffer Formation, all samples are dacites from grey metadomains with textures and mineralogies which are similar to those observed in least altered samples from McPhee Creek.

Results and discussion

Rb and Sr concentrations of volcanics in the McPhee Dome and Kelly Belt (Table 1) are similar to those from other Archaean volcanic sequences (e.g. Hallberg 1972, Hallberg *et al.* 1976, Jahn *et al.* 1974, Arth and Hanson 1975, Hawkesworth *et al.* 1975). Least altered Duffer Formation andesites and dacites have Rb contents which range from 4 to 73 ppm (mean 32 ppm) and Sr contents which range from 140 to 563 ppm (mean 301 ppm) with a mean Rb/Sr ratio of 0.11. Rb-Sr whole-rock data are given in Table 2.

Samples from McPhee Creek do not define a single isochron (Figure 2). Seven samples, including the altered metadomains, form a linear array with MSWD = 1.9. A model 3 isochron fit to these

data indicates an age of 3 018 ± 75 Ma with an initial ^{87}Sr/^{86}Sr ratio of 0.701 5 ± 0.000 7. The five least altered samples give an age of 3 471 ± 125 Ma, an initial ratio of 0.699 8 ± 0.000 9 with a MSWD of 0.92 This age is similar to that obtained from a
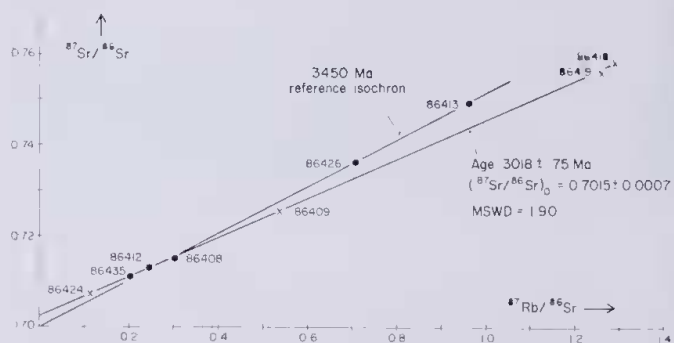

Figure 2.—^{87}Sr/^{86}Sr *vs* ^{87}Rb/^{86}Sr diagram for samples from McPhee Creek. ● = least altered sample, x = altered sample.

zircon U-Pb study of the Duffer Formation by Pidgeon (1978a). The initial ratio of 0.699 8 is close to that obtained from other suites of Archaean volcanics and to the value believed to be characteristic of the upper mantle during the early Archaean, (Jahn and Shih 1974, Moorbath 1975, Hart and Brooks 1977). Magmas erupted with initial ^{87}Sr/^{86}Sr ratios close to 0.700 0 at this time could have been derived from the upper mantle or by remelting of a short-lived source of low Rb/Sr ratio(e.g. older mafic or ultramafic volcanics). This initial ratio together with the low Rb/Sr ratio of 0.11 preclude derivation of the Duffer Formation magmas by remelting of older sialic crust. Other major and trace element data (Barley 1980) provide objections to mafic or ultramafic eclogite or amphibolite melting hypotheses (Jahn *et al.* 1981),

indicating that a process involving fractionation of a mantle-derived mafic parent magma is best able to explain the origin of this suite of felsic volcanics.

Samples from Spinaway Creek (Table 2 and Fig. 3), define an isochron with an MSWD = 0.88 to give an age of $3\,063 \pm 114$ Ma together with an initial $^{87}Sr/^{86}Sr$ ratio of $0.703\,0 \pm 0.000\,7$. It is likely that the "secondary isochrons" from McPhee Creek and Spinaway Creek with ages of $3\,018 \pm 75$ Ma and $3\,063 \pm 114$ Ma respectively, are the result of local isotopic homogenization of Sr.
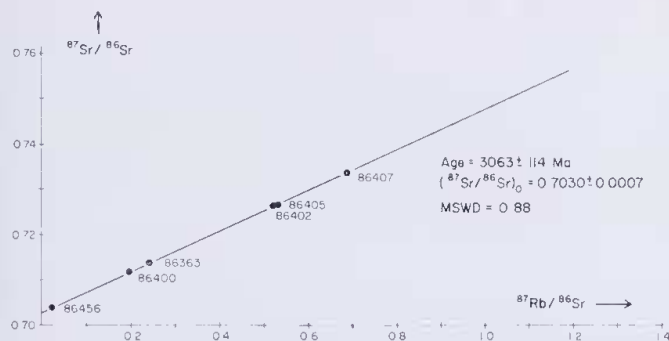

Figure 3.—$^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ diagram for samples from Spinaway Creek.

The Rb-Sr whole-rock systems of many granites and gneisses in the eastern Pilbara also appear to have been disturbed, and commonly indicate ages in the range 2 900 to 3 100 Ma (de Laeter and Blockley 1972, de Laeter et al. 1975, Pidgeon 1978h, Cooper et al. 1980).

The secondary isochron from McPhee Creek (Fig. 2) includes altered samples from pink sericite-rich metadomains which have anomalously high Rb contents (125 ppm) and Rb/Sr ratios. This observation suggests that the secondary isochrons may have resulted from either:

1. Sr isotopic homogenization during metamorphism and alteration which involved the formation of metadomains or

2. Sr isotopic homogenization (during metamorphism between 3 000 and 3 100 Ma ago) along ^{87}Sr abundance gradients generated by ageing in rocks which had previously been altered (e.g. Cameron et al. 1981).

However, because the processes capable of modifying Rb-Sr whole-rock systems are complex and not well understood, the geological significance of these secondary isochrons remains uncertain.

References

Allsopp, H. L., Ulrych, J. J. and Nicolaysen, L. O. (1968).—Dating some significant events in the history of the Swaziland System by the Rb-Sr isochron method. *Canadian J. Earth Sci.*, **5**: 605-619.

Arth, J. G. and Hanson, G. N. (1975).—Geochemistry and origin of the early Precambrian crust of north-eastern Minnesota. *Geochim. Cosmochim. Acta*, **39**: 325-362.

Barley, M. E. (1980).—Evolution of Archaean calc-alkaline volcanics: A study of the Kelly Greenstone Belt and McPhee Dome, Eastern Pilbara Block, Western Australia. Unpub. Ph.D. thesis, Univ. West Aust.

Barley, M. E. (1981a).—Relations between magma types in the Warrawoona Group: continuous or cyclic evolution? *Spec. Publs. Geol. Soc. Aust.*, **7**: 263-273.

Barley, M. E. (1981b).—Hydrothermal alteration and low-grade metamorphism of Archaean volcanic sequences in the eastern Pilbara Block. *Geol. Soc. Aust, Abstracts*, **3**: 77.

Barley, M. E., Dunlop, J. S. R., Glover, J. E. and Groves, D. I. (1979).—Sedimentary evidence for an Archaean shallow-water volcanic-sedimentary facies, eastern Pilbara Block, Western Australia. *Earth Planet. Sci. Lett.*, **43**: 74-84.

Cameron, M., Collerson, K. D., Compston, W. and Morton, M. (1981).—The statistical analysis and interpretation of imperfectly fitted Rh-Sr Isochrons from Polymetamorphic terrains. *Geochim. Cosmochim. Acta*, **45**: 1087-1097.

Cooper, J. A., James, P. R. and Rutland, R. W. R. (1980).—Rh-Sr dating of granitic intrusions in relation to the stratigraphic and deformational history of the Pilbara region. In Glover, J. G. and Groves, D. I. (eds), Extended Abstracts, Second Internat. Archaean Symp. Perth, pp. 14-15.

de Laeter, J. R. and Abercrombie, I. D. (1970).—Mass spectrometric isotope dilution analyses of rubidium and strontium in standard rocks. *Earth Planet. Sci. Lett.*, **9**: 327-330.

de Laeter, J. R. and Blockley, J. G. (1972).—Granite ages within the Archaean Pilbara Block, Western Australia. *J. Geol. Soc. Aust.*, **19**: 363-370.

de Laeter, J. R., Lewis, J. D. and Blockley, J. G. (1975).—Granite ages within the Shaw Batholith of the Pilbara Block. *Ann. Rep. Geol. Surv. West Aust. for 1974*: 73-79.

Hallberg, J. A. (1972).—Geochemistry of Archaean volcanic belts in the Eastern Goldfields region of Western Australia. *J. Petrol.*, **13**: 45-56.

Hallberg, J. A., Johnstone, C. and Bye, S. M. (1976).—The Archaean Marda igneous complex, Western Australia. *Precambrian Res.*, **3**: 111-136.

Hart, S. R. and Brooks, C. (1977).—The geochemistry and evolution of the early Precambrian mantle. *Contr. Miner. Petrol.*, **61**: 109-128.

Hawkesworth, C. J., Moorbath, S., O'Nions, R. K. and Wilson, J. F. (1975).—Age relationships between greenstone belts and "granites" in the Rhodesian Archaean craton. *Earth Planet. Sci. Lett.*, **25**: 251-262.

Hickman, A. H. (1975).—Explanatory notes on the Nullagine 1:250,000 Geological Sheet, Western Australia. *Rec. Geol. Surv. West Aust.*, **1975/5**.

Hickman, A. H. (1981).—Crustal evolution of the Pilbara Block. *Spec. Publ. Geol. Soc. Aust.*, **7**: 57-69.

Hickman, A. H. and Lipple, S. L. (1975).—Explanatory notes on the Marble Bar 1:250,000 Geological Sheet, Western Australia. *Rec. Geol. Surv. West Aust.*, **1974/20**.

Jahn, B. M. and Shih, C. Y. (1974).—On the age of the Onverwacht Group, Swaziland sequence, South Africa. *Geochim. Cosmochim. Acta*, **38**: 873-885.

Jahn, B. M., Shih, C. Y. and Murthy, V. R. (1974).—Trace element geochemistry of Archaean volcanic rocks. *Geochim. Cosmochim. Acta*, **38**: 611-627.

Jahn, B. M., Glikson, A. J., Peucat, J. J. and Hickman, A. H. (1981).—REE geochemistry and isotopic data of Archaean silicic volcanics and granitoids from the Pilbara Block, Western Australia: implications for the early crustal evolution. *Geochim. Comosmochim. Acta*, **45**: 1633-1652.

Jolly, W. T. (1980).--Development and degradation of Archaean lavas, Abitihi area, Canada, in light of major element geochemistry. *J. Petrol.*, **21**: 323-363.

Lewis, J. D. Rosman, K. J. R. and de Laeter, J. R. (1975).—The age and metamorphic effects of the Black Range dolerite dyke. *Ann. Rep. Geol. Surv. West. Aust. for 1974*: 80-88.

Lipple, S. L. (1975).—Definitions of new and revised stratigraphic units of the Eastern Pilbara Region. *Ann. Rep. Geol. Surv. West. Aust. for 1974*: 58-63.

McIntyre, G. A., Brooks, C., Compston, W. and Turek, A. (1966).—The statistical assessment of Rb-Sr isochrons. *J. Geophys. Res.*, **71**: 5459-5468.

Moorbath, S. (1975).—Constraints for the evolution of Precambrian crust from strontium isotope evidence. *Nature*, **254**: 395-398.

Page, R. W. (1978).—Response of U-Pb zircon and Rb-Sr total rock and mineral systems to low-grade regional metamorphism in Proterozoic igneous rocks, Mount Isa, Australia. *J. Geol. Soc, Aust.*, **25**: 141-162.

Pidgeon, R. T. (1978a).—3 450 m.y old volcanics in the Archaean layered greenstone succession of the Pilbara Block, Western Australia. *Earth Planet. Sci. Lett.*. **37**: 421-428.

Pidgeon, R. T. (1978b).—Geochronological investigation of granite batholiths of the Archaean granite-greenstone terrain of the Pilbara Block. Western Australia. *In* Smith, I. E. M. and Williams, J. G. (eds), Proceedings Archaean Geochemistry Conference, Toronto, University of Toronto, pp. 360-362.

Richards, J. R., Fletcher, I. R. and Blockley, J. G. (1981).—Pilbara galenas: precise isotopic assay of the oldest Australian leads; model ages and growth-curve implications. *Mineral. Deposita*, **16**: 7-30.

Sangster, D. F. and Brook, W. A. (1977).—Primitive lead in an Australian Zn-Pb-Ba deposit. *Nature*, **270**: 423.

Smith, R. E. (1968).—Redistribution of major elements in the alteration of some basic lavas during burial metamorphism. *J. Petrol.*, **9**: 191-219.

The harzburgite member of an ultramafic body in granulites, Lake Kondinin, Western Australia

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Abstract

An ultramafic body is enclosed in granulite facies metamorphic rocks, and is composed of lherzolite and harzburgite units. The harzburgite and some associated strongly feldspathic rocks are discussed in this paper. Their petrography is described, and chemical analyses of rocks and their constituent minerals are presented. The harzburgite appears to have been emplaced during the metamorphism. Deformation of orthopyroxene grains in the harzburgite suggest that it was partly crystalline during emplacement. Its chemistry suggests that it consists of two sub-units, one rather more fractionated than the other. The feldspathic rocks form small bodies of unknown form; compared with the harzburgite, they are rich in Al, Ca, Na, and, elements that are not easily accommodated in the lattices of the harzburgite minerals. The feldspathic rocks may represent either a late stage "pegmatitic" phase of the harzburgite, or be the result of an alkali metasomatism induced by later granitoid intrusive activity.

Introduction

This report further explores the theme of the author's earlier paper (Morgan 1982) concerning the emplacement of ultramafic material during high-grade metamorphism, and the retention of relic igneous structures after crystallization during the metamorphism.

Harzburgite, together with very minor bodies of plagioclase-rich rocks, are part of an ultramafic complex emplaced in high-grade Archaean gneisses (Morgan 1982), 3 km north of the Corrigin-Kondinin road, 217 km east-south-east of Perth, Western Australia (Fig. 1). The complex occurs mainly beneath a salt lake. Only very poor exposures can be seen on the western shore of the lake where, during the late 1960's, the Electrolytic Zinc Company drilled four holes into the ultramafic body. This report results from a study of diamond drill cores very kindly made available to the author by the company. The locations of the drill holes are shown in Figure 1.

In the sequence exposed by drilling (Fig. 2), harzburgite occurs "down-hole" from the felsic gneiss exposed in DDH C2 and C4, and "up-hole" from lherzolite exposed in DDH C4 and C5. The feldspathic rocks form small bodies of unknown form within the harzburgite, and consist of an anorthosite and two magnetitebiotite andesinites. As will be discussed in a later section, the harzburgite is considered to have been emplaced after the lherzolite described by Morgan (1982).

The harzburgite unit

Petrographic study of the cores of DDH C3, C4, and C5 supplemented by rock and mineral analyses, shows that the harzburgite consists of two sub-units, megacrystic harzburgite, and lenticular-textured harzburgite. Close to its contact with the lherzolite (Fig. 2), the magacrystic harzburgite has a textural variant, referred to as radial pyroxene harzburgite. DDH C2 was not examined, due to lack of time and facilities.

Petrography

Minerologically, the harzburgite consists of olivine, orthopyroxene, magnetite, and minor quantities of phlogopite. Averages of modal analyses from each of the sub-units are shown in Table 1. Modal analyses of individual samples are considered meaningless and not tabulated, because of the irregular distribution through the core of orthopyroxene megacrysts and lenticular aggregates.

Serpentinization of both olivine and orthopyroxene is almost complete in DDH C3. The original mineralogy can, however, be easily deduced from the textural and pseudomorphous appearance of the serpentine. In DDH C4 and C5, serpentinization affects between 20% and 80% of the samples examined. In the uppermost 80 m to 90 m of all the cores, serpentinized harzburgite is very strongly silicified and ferruginized.
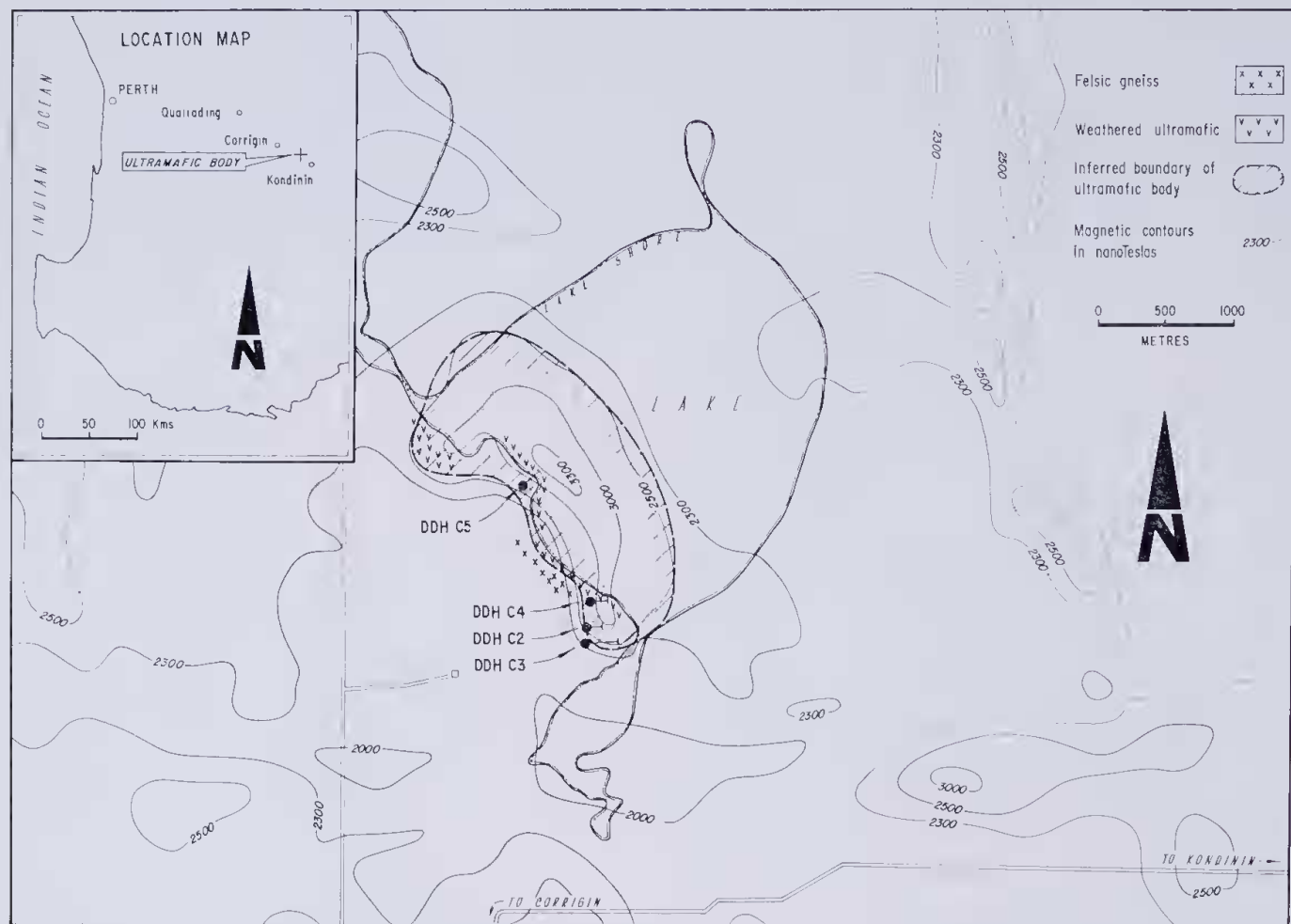
Figure 1.—Simplified aeromagnetic anomaly map of the ultramafic near Lake Kondinin. Reproduced by permission of the Electrolytic Zinc. Co. of Australasia. *Inset*: Location map, South Western Australia.

Megacrystic harzburgite.

The extent of the magacrystic harzburgite is shown in Figure 2. In this rock, megacrysts of orthopyroxene, ranging up to 20 mm long, are enclosed in a matrix of polygonal olivine and orthopyroxene grains that have an average diameter of 1 mm. In the southernmost drill hole (C3) the megacrysts are euhedral prismatic, and have a preferred orientation. Although they are almost completely serpentinized, inset relics of orthopyroxene in any one megacryst are in complete optical continuity, indicating that they are unstrained. Relics of olivine in the serpentinized matrix likewise show no evidence of deformation.

However, in DDH C4 and C5, the orthopyroxene megacrysts are commonly strained, with mosaic substructure and, more rarely, kink-banding. Very often they are polygonized to aggregated of strain-free grains on their margins. Particularly in DDH C5—the northernmost hole—the megacrysts tend to be almost completely polygonized, with the constituent grains of the aggregates showing a preferred orientation. In the matrices of these rocks, olivine and orthopyroxene are almost entirely unstrained. Where

not obscured by serpentinization, the matrix texture is polygonal, with the grains having curvilinear to straight boundaries meeting in triple points. Here and there, incomplete crystallization equilibrium is suggested by sub-amoeboid grain boundaries.

Magnetite occurs as granular to sub-amoeboid grains, 0.2 to 1 mm in diameter. Phlogopite, where it occurs, forms subhedral, nearly colourless books that tend to have a preferred orientation parallel to that of the orthopyroxene megacrysts.

Table 1

Harzburgite Modal Analyses

	Mega-crystic	Radial Pyroxene	Lenticular	Average
Olivine	67·7	72·2	69·3	69·7
Orthopyroxene	24·5	21·8	20·5	27·3
Magnetite	5·8	3·9	5·9	5·2

Radial pyroxene harzburgite is a textural variant of megacrystic harzburgite, because they are geochemically similar to each other, whereas the lenticular-textures harzburgite shows significant differences in both composition and texture. The radial pyroxene harzburgite is adjacent to the contact of harzburgite with lherzolite in DDH C4 and C5. It contains sub-radial growths of orthopyroxene measuring up to 15 cm across. Within the growths, sub-radiating, thin orthopyroxene grains are elongated nearly parallel to their crystallographic c-axes, their grain boundaries being finely sutured. Some mosaic sub-structure is seen in places, but otherwise there is little evidence of deformation. The associated olivine is strongly serpentinized; relic grains suggest that their sizes range up to 10 mm, that they have an amoeboid shape, and that they are entirely unstrained.

Figure 2.—Schematic diagram, from diamond drill hole data, of the relationships between the megacrystic, lenticular, and radial pyroxene harzburgite.

Lenticular-textured harzburgite.

The core samples display a lenticular-banded appearance. The lenticles—composed of orthopyroxene—measure up to 1.5 cm wide by 4 cm long, and are enclosed in an olivine-rich matrix. In some cores, particularly around 100 m depth in DDH C5, the lenses form tight, isoclinal folds.

In section, the lenses are seen to consist of aggregates of polygonal orthopyroxene grains showing no strain whatsoever. The matrix olivine, where it is not strongly serpentinized, is also polygonal and strain-free. The very sparse phlogopite flakes have a preferred orientation parallel to the lenses.

Chemistry

Major and some minor element analyses of five samples of harzburgite are presented in Table 2. Each analysis was made from a representative sample taken from 1.5 m lengths of core, in an attempt to balance out the irregular distribution of orthopyroxene.

The harzburgite samples consist essentially of SiO_2, iron oxides, and MgO, with only very minor quantities of the other oxides when compared with ultramafics in alpine-type bodies (eg. Loney *et al.* 1971), high temperature peridotites (eg. Green 1964), ultramafic nodules (eg. Carswell and Dawson 1970), komatiitic peridotites (eg. Nesbitt and Sun 1976), and the ultramafic portions of layered gabbroic intrusives (eg. Hess 1960, Hall 1932).

There are differences between the lenticular-textured and magacrystic sub-units of the harzburgite. The lenticular-textured harzburgite is poorer in Cr, Ni, Co, V, and Zn. However, the most significant difference is in the Fe/Mg ratios. In the megacrystic sub-unit, these range between 0.55 and 0.69, distinctly higher than the value of 0.45 in the lenticular harzburgite. The differences suggest that the sub-units represent two different—though possibly related—intrusives, one of which (the megacrystic sub-unit) is rather more fractionated than the other.

The least differentiated members of the lherzolite unit's cycles all contain more Al_2O_3 and CaO (Morgan 1982). Their Fe/Mg ratios (0.57-0.70), however, fall within the range of the megacrystic harzburgite.

Mineral chemistry

Electron microprobe analyses of olivine, orthopyroxene, and magnetite are presented in Tables 3, 4, and 5 respectively. All analyses were carried out by the author with the W.A. Institute of Technology's Seimens Etec Microprobe analyser, using an accelerating voltage of 20 kV, a specimen current of 0.25 x 10^{-7} amps, and a 1 - 2 um beam diameter. X-ray intensities were converted to oxide percentages using the Magic IV programme.

Olivine (Table 3)

The Mg/(Mg + Fe) ratios range between 0.90 and 0.95, i.e., within the range of olivines from alpine-type ultramafics, and distinctly more Mg-rich than those from the lherzolite unit (Morgan 1982), as will be seen from Figure 3, or from the layered intrusives (eg. Green 1964, Cameron 1978). Olivines from the lenticular-textured harzburgite contain more Mg than those from the megacrystic sub-unit.
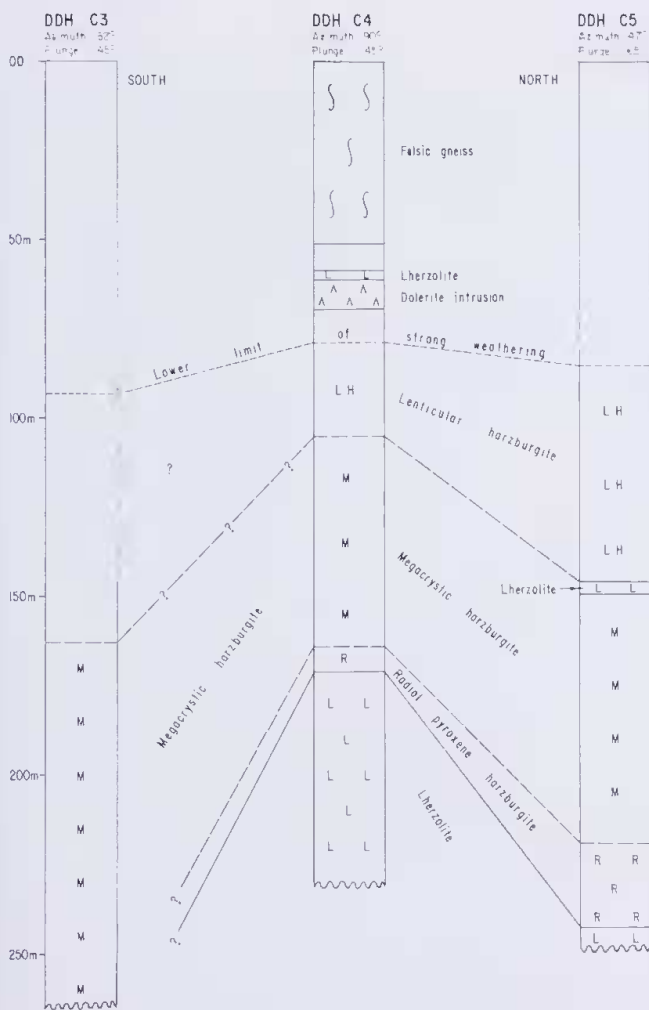
Table 2

Analyses and Norms of the harzburgites

	Megacrystic Harzburgite			Lenticular-textured Harzburgite	
Drill Hole	C4	C4	C4	C4	C5
Depth	169·3m	156·4m	125·9m	101·7m	115·8m
SiO_2	36·87	38·93	40·58	41·05	36·05
TiO_2	0·04	0·07	0·04	0·06	0·06
Al_2O_3	0·37	0·38	0·32	0·40	0·64
Fe_2O_3	7·98	11·71	8·88	6·77	9·04
Cr_2O_3	0·95	N.D.	1·07	0·83	0·84
FeO	7·49	8·58	7·09	6·51	4·81
MnO	0·22	0·18	0·20	0·19	0·28
MgO	34·12	36·03	32·33	35·95	37·06
NiO	0·29	N.D.	0·29	0·22	0·25
CaO	0·30	0·13	0·18	0·24	0·03
Na_2O	0·04	0·03	0·06	0·05	0·03
K_2O	0·04	0·05	0·03	0·09	0·01
P_2O_5	0·002	N.D.	0·01	0·01	0·01
Loss	10·77	3·60	8·11	6·85	11·00
Total	99·48	99·69	99·19	99·21	100·11
Co	248	N.D.	249	201	217
Cr	6 510	N.D.	7 348	5 678	5 722
Ni	2 300	N.D.	2 250	1 700	2 000
V	23	N.D.	17	8	12
Zn	130	N.D.	135	80	75
Fe/Mg	·554	·685	·601	·451	·450
or	0·22	0·28	0·17	0·56	0·06
ab	0·37	0·26	0·52	0·42	0·26
an	0·70	0·64	0·50	0·58	0·08
C	....	0·02	. .	....	0·45
di—Wo	0·33	....	0·14	0·23	....
en	0·27	....	0·11	0·19	....
fs	0·03	....	0·001	0·01	....
hy—en	27·76	31·74	45·74	37·24	25·82
fs	2·35	2·23	3·18	2·61	0·42
ol—fo	39·90	40·63	24·29	36·53	46·59
fa	3·73	3·14	1·85	2·83	0·86
il	0·08	0·14	0·08	0·12	0·12
mt	11·58	16·97	12·87	9·82	13·12
ct	1·41	....	1·57	1·23	1·23
ap	0·003	....	0·02	0·02	0·02
Loss	10·77	3·60	8·11	6·85	11·00
Total	99·50	99·65	99·15	99·24	100·03

Analyst: S.G.S. Australia Pty. Ltd., Perth.

N.D.—No Data

The distribution of Mg and Fe between olivines and their co-existing orthopyroxenes is fairly uniform (Fig. 3), the values of $K_D \dfrac{Fe/Mg \; opx}{Fe/Mg \; ol}$ having an average of 1.05 and a range of 0.9 to 1.2. The values are close to those of Morgan (1982), Frost (1975), Challis (1965), and Green (1964).

Ti, Al, Cr, Ca, Na and K are low or absent, Mn is low, and Ni shows, as one would expect, a preference for olivine over orthopyroxene.

Orthopyroxene (Table 4)

The Mg/(Fe + Mg) ratios range between 0.895 and 0.95. Like the olivines, these values are distinctly higher than those of the lherzolite unit (see Fig. 3), which range between 0.79 and 0.89. Orthopyroxenes from the lenticular-textured sub-unit are more Mg-rich than those of the megacrystic harzburgite.

The harzburgite orthopyroxenes are low in Al, Ca, Cr, and Ti, when compared with those in the lherzolite unit (Morgan, 1982), alpine (eg. Loney et al. 1971), nodule (eg. Boyd et al. 1976, Dawson et al. 1970), and layered intrusion harzburgites (Cameron 1978). This, of course, is a condition imposed by the host rocks, which are themselves poor in these elements.

Magnetite (Table 5)

Total iron was analysed as Fe_2O_3; Fe^{+2} and Fe^{+3} were calculated assuming ideal stoichiometry. The magnetite, like that in the lherzolite unit (Morgan 1982) is chromiferous, with Cr being concentrated in this mineral, very little being in the co-existing orthopyroxene. Al_2O_3 ranges between 0.70% and 2.18%. Al_2O_3 is very low in the harzburgite rock analyses (Table 2), but, like Cr. is concentrated in magnetite rather than in the associated silicate phases. MgO ranges between 0.4% and 4.46%; Mg/(Mg + Fe^{+2}) ratios tend to be rather higher in the lenticular-textured harzburgite sample when compared with those of the megacrystic sub-unit.

Table 3

Electron microprobe analysis of olivine.

Analyst: W. R. Morgan

| | Megacrystic Harzburgite | | | | Lenticular-textured Harzburgite | | | |
| | DDH C4 | | | | | | | DDH C5 |
Depth	169·3 m	156·4 m	146·9 m	143·8 m	101·7 m	99·7 m	94·5 m	115·8 m
SiO₂	42·14	40·49	40·23	40·70	41·85	41·82	41·79	39·80
TiO₂	Nil	0·05	0·02	0·02	Nil	Nil	Nil	0·04
Al₂O₃	Nil	0·13	0·09	Nil	0·20	0·10	0·19	0·19
Cr₂O₃	Nil	0·01	0·03	Nil	0·05	0·06	0·01	0·01
FeO	9·35	10·21	9·37	9·09	6·92	7·36	6·43	4·47
MnO	0·25	0·21	0·19	0·23	0·19	0·20	0·14	0·27
NiO	0·56	0·49	0·32	0·33	0·30	0·52	0·49	0·44
MgO	47·10	49·11	49·37	50·05	50·95	50·06	51·38	53·75
CaO	Nil	0·01	0·01	0·02	0·03	0·01	Nil	Nil
Na₂	Nil	0·01	0·14	Nil	Nil	0·08	0·08	0·08
K₂O	Nil	Nil	Nil	Nil	Nil	Nil	0·01	0·04
Total	99·40	100·73	99·77	100·43	100·48	100·22	100·53	99·09

Numbers of ions on the basis of 4 oxygens

|								
Si	1·034	·990	·989	·992	1·007	1·012	1·004	·968
Al	....	·004	·003	....	·006	·003	·005	·006
Ti	....	·001	·001	·001	....	....	. .	·001
Fe	·192	·209	·193	·185	·139	·149	·129	·091
Cr	....	Tr	·001	....	·001	·002	Tr	Tr
Mn	·005	·004	·004	·005	·004	·004	·003	·006
Ni	·011	·010	·006	·006	·006	·010	·010	·009
Mg	1·723	1·789	1·809	1·818	1·827	1·805	1·840	1·947
Ca	....	Tr	Tr	·001	·001	Tr	..	....
Na	....	Tr	·007	....	....	·004	·004	·004
K	....	. .	....	....	..		Tr	·001
Mg	10·0	10·5	9·6	9·2	7·1	7·6	6·6	4·5
Fe	90·0	89·5	90·4	90·8	92·9	92·4	93·4	95·5
Mg/(Fe + Mg)	·900	·895	·904	·908	·929	·924	·935	·955
Fe/(Fe + Mg)	·100	·105	·096	·092	·071	·076	·066	·045
Fe/Mg	·111	·117	·107	·012	·076	·083	·070	·046
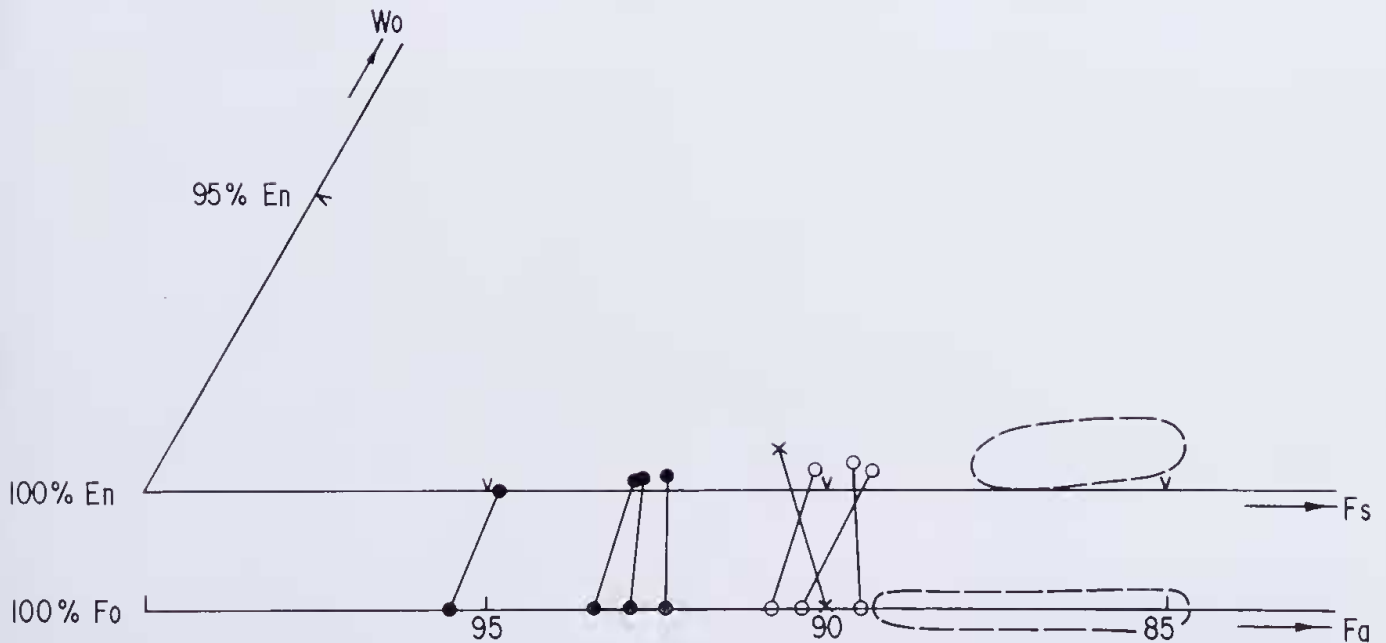
Figure 3.—Plot of co-existing olivines and orthopyroxenes. Filled Circles: lenticular harzburgites; Open Circles: megacrystic harzburgites; x: radial pyroxene harzburgite: Dashed outline areas: olivines and orthopyroxenes in the lherzolite unit (Morgan 1982).

Table 4

Electron microprobe analyses of orthopyroxene.
Analyst: W. R. Morgan

| | Megacrystic Harzburgite | | | | | | Lenticular-textured Harzburgite | |
| | | | | DDH C4 | | | | DDH C5 |
Depth	169·3 m	156·4 m	146·9 m	143·8 m	101·7 m	99·7 m	94·5 m	115·8 m
SiO_2	58·27	56·69	58·84	57·04	58·23	58·39	59·35	58·38
TiO_2	Nil	0·02	0·01	0·04	0·04	Nil	0·05	0·05
Al_2O_3	0·53	0·11	0·45	0·23	0·19	0·41	0·44	0·66
Cr_2O_3	0·05	0·13	0·08	0·03	0·05	0·05	0·06	0·22
FeO	6·21	7·00	7·05	6·81	4·86	5·21	4·84	3·56
MnO	0·25	0·21	0·23	0·28	0·20	0·22	0·23	0·31
NiO	0·12	0·09	0·05	0·11	0·04	0·10	0·07	0·04
MgO	34·93	34·79	33·58	35·59	35·30	36·07	35·46	36·27
CaO	0·34	0·28	0·14	0·17	0·11	0·13	0·11	0·03
Na_2O	Nil	0·07	0·03	0·01	Nil	Nil	Nil	0·05
K_2O	Nil	0·01	Nil	0·01	Nil	Nil	Nil	0·01
Total	100·70	99·38	100·26	100·32	99·02	100·58	100·63	99·38

Numbers of ions on the basis of 6 oxygens

	169·3 m	156·4 m	146·9 m	143·8 m	101·7 m	99·7 m	94·5 m	115·8 m
Si	1·993	1·997	2·019	1·969	2·009	1·989	2·013	1·997
Al^{iv}	·007	·005	...	·009	....	·011	....	·003
Al^{vi}	·014	....	·018	....	·008	·006	·018	·023
Ti	..	·001	Tr	·001	·001	....	·001	·001
Fe	·178	·204	·202	·197	·140	·149	·137	·101
Cr	·002	·004	·001	·001	·001	·002	·002	·006
Mn	·007	·006	·007	·008	·006	·006	·007	·009
Ni	·003	·003	·001	·003	·001	·003	·002	·001
Mg	1·780	1·808	1·717	1·831	1·815	1·832	1·793	1·837
Ca	·013	·011	·005	·006	·004	·005	·004	·001
Na	..	·002	·002	·001	....	....	..	·003
K	....	Tr	....	Tr	....	....	....	Tr
Mg	90·3	89·4	89·2	90·0	92·6	92·2	92·7	94·7
Fe	9·0	10·1	10·5	9·7	7·2	7·5	7·1	5·2
Ca	0·7	0·5	0·3	0·3	0·2	0·3	0·2	0·1
Mg/(Mg + Fe)	·909	·899	·895	·903	·928	·925	·929	·948
Fe/(Mg + Fe)	·091	·101	·105	·097	·072	·075	·071	·052
Fe/Mg	·100	·113	·118	·108	·077	·081	·076	·055

Table 5

Electron microprobe analyses of magnetite.
Analyst: W. R. Morgan

| | Megacrystic Harzburgite | | | | | | Lenticular-textured Harzburgite | |
| | | | | DDH C4 | | | | DDH C5 |
Depth	169·3 m	156·4 m	147·5 m	143·8 m	101·7 m	99·77 m	94·5 m	115·8 m
TiO_2	0·16	0·39	0·02	0·19	0·29	0·10	0·07	0·26
Al_2O_3	2·11	1·74	0·94	0·70	1·15	1·43	0·94	2·18
Cr_2O_3	13·61	7·20	7·77	5·52	12·43	9·01	7·95	8·29
Fe_2O_3	54·69	59·96	59·65	62·62	56·17	58·88	60·47	59·72
FeO	27·62	28·04	30·13	29·07	25·60	27·68	27·04	24·38
MgO	2·80	2·21	0·40	1·29	3·59	2·31	2·61	4·46
Total	101·00	99·94	98·91	99·39	99·23	99·41	99·08	99·29

Numbers of ions on the basis of 32 oxygens

	169·3 m	156·4 m	147·5 m	143·8 m	101·7 m	99·77 m	94·5 m	115·8 m
Al	·730	·616	·341	·252	·404	·507	·335	·758
Cr	3·155	1·708	1·889	1·330	2·929	2·142	1·899	1·932
Fe^{3}	12·069	13·541	13·806	14·361	12·600	13·323	13·747	13·252
Ti	·035	·088	·004	·046	·063	·023	·016	·058
Mg	1·223	·988	·185	·586	1·594	1·035	1·175	1·960
Fe^{+2}	6·777	7·038	7·751	7·409	6·382	6·962	6·831	6·012

The feldspathic rocks

There are three very minor occurrences of unusual plagioclase-rich rocks within the harzburgite unit. All are intersected by DDH C5. The occurrences are:

216.3 m-215.7 m Biotite-magnetite-andesine rock.
187.7 m-187.2 m Biotite-andesine rock.
157.3 m-157.4 m Spinel-bearing anorthite rock.

Structure and relationships

A few points can be noted:

(1) There is strong alteration of the harzburgite on both sides of the anorthite rock. Such alteration occurs only on the "down-hole" side of the andesine rocks. The alteration takes the form of talcose, serpentine material that provided very little core recovery.

(2) Internally, the anorthite body is the most simple: a thin zone of anorthite rock is bounded on the "up-hole" side only by a selvage of phlogopite.

(3) The two andesinic rocks are more complex. That at 187 m has a bilateral zonation: a central zone of soft clay-sericite material is bounded either side by successive zones of biotite, biotite-plagioclase, and biotite. The occurrence at 216 m is rather less symmetrical. A central zone of incompletely recovered micaceous rock has zones of magnetite and biotite-magnetite-andesine rock either side of it. The "uphole" margin is composed of magnetite-biotite rock, and the "down-hole" side of a biotite-sericite rock which may represent a hydrothermally altered biotite-plagioclase rock.

(4) The form of the bodies is not known. Prider (1945) reported hypersthene andesine rock forming a segregation within hornblende hypersthenite at the Dangin railway cutting, 80 km north-north-west of Lake Kondinin. However, whether the Lake Kondinin occurrences are segregations or intrusive bodies is difficult to tell from the core samples available.

Petrography

Anorthite rock: 157 m. The upper marginal zone consists of crumpled, nearly colourless flakes of phlogopite that show a rough preferred orientation parallel to the contact with the anorthite rock. Accessory zircon is present.

The plagioclase rock consists almost entirely of polygonal grains of anorthite ranging between 0.1 and 1.5 mm in size. Very minor quantities of weakly pleochroic biotite are present. Irregularly zoned green to brown spinel forms grains about 0.2 mm across the triple junctions of plagioclase grains. Also present are very thin stump prisms of apatite, and grains of a metamict mineral that perhaps represents zircon.

Biotite-andesine rock: 187.2-187.7 m. The micaceous zones are composed of very pale brown, intergrown mica flakes measuring up to 3 mm across. The flakes are strongly contorted and the edges are crumpled and even fragmented.

The two zones of biotite-andesine rock are very similar. Plagioclase forms angular to amoeboid grains ranging between 0.5 and 10 mm across; in a few grains, the twin lamellae are slightly strained. Biotite is pleochroic from pale-brown to mud-brown, and forms sub-tabular to anhedral flakes that are frequently clustered, and which—particularly in the upper zone—show a preferred orientation parallel to the contacts. Accessory apatite and zircon are present.

Biotite-magnetite-andesine rock: 215.7-216.3 m The micaceous margin is very similar to that described above. The andesine rocks contain polygonal plagioclase grains 0.5 to 2 mm in size, along with amoeboid magnetite grains up to 5 mm across, and subhedral, randomly oriented books of biotite about 1 mm long. Accessory prismatic apatite and sub-rounded zircon are present.

The lowermost zone is probably heavily altered andesine rock: the plagioclase is replaced by extremely fine-grained clay minerals which occur as a matrix forming about 70% of the rock, and which encloses subhedral biotite flakes up to 1 mm long, and minor amounts of magnetite. Accessory apatite and zircon are present.

Chemistry (Table 6)

Two samples, at 215.6 m and 187.8 m—are fairly similar to each other, except that the sample at 187.8 m contains 52% SiO_2, and that at 215.5 m has 45% SiO_2; the sample from 215.6 m has 5% Fe_2O_3, a reflection of the presence of magnetite. Otherwise, these rocks have moderate to low FeO and MgO. Compared with the harzburgites, they have high Al_2O_3, CaO, Na_2O, and K_2O—in fact, those elements that are not easily accommodated in the lattices of the harzburgite minerals.

The anorthite rock at 157.3 m is particularly rich in CaO and Al_2O_3 with small amounts of MgO; all the other oxides are very low in amount.

All three samples are undersaturated, and contain nepheline in their norms.

Mineral chemistry (Table 7)

The *plagioclase* at 215.5 m and 187.8 m is andesine; that at 157.3 m is anorthite. All three contain very little K_2O. *Phlogopite*, when compared with the examples in Deer, Howie and Zussman (1962), contain rather more SiO_2, Al_2O_3, total iron oxide and Na_2O, and somewhat lower MgO and K_2O. The *spinellid* at 215.5 m is virtually pure magnetite, containing only minor quantities of Ti, Al, Cr, and Mg. That at 157.3 m is a pleonaste; it contains only minor Fe^{+3} and trace quantities of Ti and Cr.

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Table 6

Analyses and norms of the anorthositic Rocks, DDH C5.
Analyst: S.G.S. Australia Pty. Ltd.. Perth.

Depth				215·5 m	157·3 m	187·8 m
SiO_2	....	....	....	45·18	43·40	51·85
TiO_2	....	....	....	0·41	0·04	0·46
Al_2O_3	....	....	....	22·20	33·55	23·15
Fe_2O_3	....	....	....	5·04	0·26	0·35
Cr_2O_3	....	....	....	Tr	N.D.	0·02
FeO	....	....	....	3·67	0·45	2·53
MnO	....	....	....	0·05	0·01	0·02
MgO	....	....	....	5·04	1·72	6·54
NiO	....	....	....	0·03	0·01	0·04
CaO	....	....	....	6·18	17·03	5·85
Na_2O	....	....	....	4·99	0·97	5·12
K_2O	....	....	....	1·64	0·53	2·29
P_2O_5	....	....	....	0·35	0·17	0·09
Loss	....	....	....	2·42	1·90	1·98
Total	...		....	100·20	100·04	100·29
Ba	....	....	....	780	220	490
Co	....	....	....	46	N.D.	N.D.
Cr	....	....	....	27	N.D.	107
Ni	....	....	....	200	90	320
V	....	....	....	32	N.D.	<5
Zn	....	....	....	10	N.D.	N.D.
Ne	....	....	....	4·23	2·05	5·57
or	....	....	....	9·68	3·12	13·52
ab	....	....	....	34·39	4·57	33·03
an	....	....	....	28·34	83·36	28·45
c	....	....	....	1·82	0·83	1·83
ol—						
fo	....	....	....	8·79	3·01	11·41
fa	....	....	....	1·59	0·45	2·85
il ...	....	....	....	0·77	0·08	0·88
mt	....	....	....	7·32	0·37	0·51
ct	....	....	....	....	....	0·02
ap	....	....	....	0·84	0·40	0·20
Loss	....	....	....	2·42	1·90	1·98
Total	....		....	100·20	100·14	100·25

Discussion

The petrogenesis of the harzburgite and the feldspathic rocks must be considered in relation to the lherzolite (Morgan 1982), because all three form parts of the same ultramafic body.

Harzurgite-lherzolite relationship

The harzburgite occurs in the drill cores, stratigraphically, above the cyclic layering in the lherzolite. Hence, it cannot be regarded as an early crystal cumulate that preceded the lherzolite.

Three features, noted from drill hole data, and from outcrop on the western lake shore, strongly suggest that the harzburgite was emplaced after the lherzolite. First, mapping along the shore line showed the presence of three bodies of lherzolite. One is in contact with the gneissic country rock, but is partly enclosed by harzburgite. The others are entirely enclosed by harzburgite. They measure from 20 m by 25 m up to 50 m by 350 m, and are elongated parallel to the contact with the gneiss, They appear to be contact remnants and rafts isolated by the intrusion of the harzburgite.

Second are the occurrences at 58 m to 61 m and 149 m to 151 m both in DDH C5 of lherzolite, enclosed within harzburgite. These, following on from the field observations just described, are thought to be rafts of lherzolite intersected by the drilling.

Table 7

Mineral analyses, feldspar rocks, DDH C5.
Analyst: W. R. Morgan

	Plagioclase				Biotite				Spinellids				Zircon	
Depth	157·3 m	187·8 m	215·5 m	Depth	157·3 m	187·8 m	215·5 m	Depth		157·3 m	215·5 m	Depth		187·8 m
SiO_2	44·39	57·08	58·14	SiO_2	40·23	44·75	41·87	TiO_2		0·03	0·01	SiO_2		30·98
Al_2O_3	35·26	26·33	25·68	TiO_2	0·34	1·91	2·17	Al_2O_3		63·49	0·12	ZrO_2	....	66·21
Fe_2O_3	0·14	0·20	0·15	Al_2O_3 ...	20·75	14·69	16·71	Cr_2O_3	..	0·02	0·05	TiO_2	..	0·03
MgO	Nil	0·03	0·02	Cr_2O_3 →	Nil	0·07	0·01	Fe_2O_3	.	2·21	68·90	Al_2O_3	...	1·13
CaO	19·66	8·52	8·59	FeO	4·81	8·92	7·97	FeO	..	17·87	31·42	Fe_2O_3	...	0·30
Na_2O	0·84	6·90	6·58	MnO ..	0·02	0·07	0·14	MgO	..	15·45	0·02	MnO	...	0·03
K_2O	0·01	0·02	0·06	NiO . .	Nil	0·08	Nil					MgO	. .	0·01
				MgO .	23·78	20·14	20·82			99·07	100·52	CaO	..	0·15
	100·31	99·11	99·00	CaO .	0·03	0·01	Nil					ThO_2	..	0·09
				Na_2O . .	2·18	1·30	1·33					P_2O_5	....	0·07
				K_2O	7·10	8·20	8·19							
					99·24	100·14	99·21							99·00

Number of ions

		32 oxygens				24 oxygens					32 oxygens				16 oxygens	
Si	....	8·202	10·330	10·481	Si	5·403	6·059	5·725	Al		15·674	·043	Si	....	3·833
Al	...	7·681	5·618	5·458	Al^{iv} ..	2·597	1·941	2·275	Cr	...	·003	·012	Zr	....	3·995
Fe^{+3}	. .	·019	·028	·020	Al^{vi}	·688	·407	·419	Fe^{+3}	...	·348	15·987	Ti	....	·003
Mg	....		·008	·004	Ti	·034	·195	·223	Ti	..	·005	·002	Al	....	·165
Ca	....	3·893	1·652	1·660	Cr .		·001	·001	Mg	..	4·822	·009	Fe^{+3}	....	·028
Na	. .	·302	2·421	2·301	Fe^{+2} .	·540	1·739	1·822	Fe^{+2}	....	3·129	8·057	Mn	....	·003
K	....	·002	·004	·013	Mn .	·002	·008	·016					Mg	....	·002
					Ni		·008						Ca	....	·020
Ab	....	7·2	59·4	57·9	Mg	4·760	4·070	4·243					Th	....	·003
An	....	92·7	40·5	41·8	Ca	·004	·002						P ..	....	·007
Or	....	·1	0·1	0·3	Na	·568	·342	·353							
					K	1·217	1·419	1·428							

Third, the radial pyroxene harzburgite, adjacent to the Harzburgite-lherzolite contact in DDH C4 and C5 is believed to be a contact facies, caused partly by the strain and physical disruption of near solidfied harzburgite magma during emplacement against lherzolite. It is suspected that the subradial structures of unstrained orthopyroxene evolved by recrystallization due, perhaps, to heat derived from solid, but still hot, lherzolite. This would imply that there was no great time gap between the emplacement of the lherzolite and the harzburgite.

Harzburgite-gneiss relationship

The gneissic country rocks occur at the tops of the drill cores in DDH C2 and C4. However, the contact relations exposed by the drilling are inconclusive (Morgan 1982). However, evidence from the very poor lake shore exposures show that the harzburgite intrudes the gneisses. Detailed mapping carried out by geology students from the Western Australian Institute of Technology, under the author's direction, at the north-west shore showed a trail of four bodies of andradite-salite-anorthite rock extending over 200 m within strongly serpentinized harzburgite, aligned parallel to the contact with the gneiss.

Modal and chemical analyses of this material, together with electron microprobe analyses of the constitutent minerals, are given in Table 8. From these data, it is considered that these bodies are xenoliths of calc-silicate metasedimentary rocks.

Harzburgite emplacement

The megacrystic harzburgite

In this unit, the large orthopyroxene grains show the results of considerable deformation—lattice strain, mosaic substructure, to complete polygoniza-tion—in the northerly diamond drill core (DDH C5). It could be argued that this unit was emplaced prior to tectonism, with the deformation resulting from the tectonism. However, the megacrysts in DDH C3 (the most southerly drill hole) are euhedral and unstrained, which strongly suggests that they were phenocrysts in a magma that was emplaced after tectonism. Their deformation in the northerly cores thus suggests that the ultramafic magma was crystallizing during intrusion, with the still largely liquid material in the vicinity of DDH C3 pushing northwards against partly to mostly crystallized magma in the vicinity of DDH C4 and, more particularly, DDH C5.

The lenticular-textured harzburgite

The origin of this unit is much more difficult to explain, principally because its relationship to the megacrystic harzburgite is unknown. In composition, it is rather more Mg-rich than the megacrystic harzburgite, being closer to the alpine-type ultramafics. However, the ultramafic body as a whole—including the lherzolite and the megacrystic harzburgite—is certainly not alpine-type.

An explanation that could satisfy both its textural characteristics and its more magnesian character is to regard it as an early-crystallized part of the harzburgite, chilled against the relatively cool gneisses. The zone containing the lenticles, which, in DDHC4, extends 80 m to 105 m depth, would

Table 8

Xenolithic calc-silicate rock: modal and chemical analyses of the rock, and chemical analyses of its constituent minerals

Rock

	Mode				*Chemical		
Anorthite	....	....	53·2	SiO₂	....	....	43·3
Salite	....	....	27·1	TiO₂	....	....	1·25
Andradite	....	....	20·2	Al₂O₃	....	....	18·5
			100·0	Fe₂O₃	....	....	5·18
				FeO	....	....	3·05
				MnO	....	....	0·26
				MgO	....	....	4·25
				CaO	....	....	22·9
				Na₂O	....	....	0·36
				K₂O	....	....	0·02
				LOI	....	....	0·49
				Total	....	....	99·56

Minerals

			§Andrad-ite	§Salite	§Anorth-ite
SiO₂	....	....	36·18	49·96	44·24
TiO₂	....	....	1·04	0·12	0·01
Al₂O₃	....	....	6·19	2·76	33·91
Cr₂O₃	....	....	0·08	0·01	0·01
Fe₂O₃	....	....	21·47†		0·45†
FeO	....	....	..	11·44‡	....
MnO	....	....	0·57	0·55	0·04
NiO	....	....	0·01	0·01	0·02
MgO	....	....	0·29	10·67	0·03
CaO	....	....	32·98	23·27	19·70
Na₂O	....	....	0·24	0·32	0·76
K₂O	....	....	Nil	0·02	0·02
Total	....	....	99·06	99·13	99·18

Numbers of ions:			24 oxygens	6 oxygens	32 oxygens
Si	....	....	5·960	1·919	8·264
Alⁱᵛ	....	....	0·040	0·081	7·539
Alᵛⁱ	....	....	1·150	0·043	....
Ti	....	....	0·139	0·004	0·002
Fe	....	....	2·635†	0·368‡	0·064†
Cr	....	....	0·098	0·001	0·002
Mn	....	....	0·792	0·018	0·007
Ni	....	....	0·001	Tr	0·003
Mg	....	....	0·710	0·611	0·008
Ca	....	....	5·822	0·958	3·961
Na	....	....	0·077	0·024	0·277
K	....		....	0·001	0·005

*Analyst: S.G.S. Australia Pty. Ltd. Perth. §Analyst: W. R. Morgan, W.A.I.T. †Total iron calculated as Fe₂O₃(Fe⁺³). ‡Total iron calculated as FeO (Fe⁺²)

represent deformed, mostly crystallized material dragged by the motion of the more liquid megacrystic harzburgite. The gneissic country rock, at the height of granulite metamorphism, would have had temperatures of around 760° to 900°C (Hewins 1975). A partly crystallized harzburgite magma with, say, 20% to 30% crystals, would have a temperature between 1 400-1 700°C (Ito and Kennedy 1967).

However, this argument suffers because there is nothing chemically or texturally equivalent to the lenticular-textured harzburgite adjacent to the lherzolite. It may be therefore, that the lenticular-textured harburgite represents a third intrusive body, younger that the lherzolite, but whose age relationship to the megacrystic harzburgite is not known.

Interpretation of textures

The writer (Morgan 1982) discussed the petrography of the lherzolite unit in terms of metamorphic textures superimposed on relic igneous structures. In the discussions above, he has stressed the igneous emplacement of the harzburgite, using the deformation of megacrysts and other features to support his argument. Nevertheless, apart from the megacrysts, textural features of the harzburgite have a metamorphic appearance. Even in rocks where the megacrysts display strong straining and sub-mosaic structures, the matrix grains are entirely unstrained, and have curvilinear to straight-line boundaries, i.e., the grain shapes range from amoeboid to polygonal.

The causes of the metamorphic texture are probably two-fold. First, the effect of the heat of the intrusion itself annealing matrix crystals strained whilst emplacement of the crystal mush was taking place. Second, the effect of the continuing heat of the regional metamorphism of the country rocks enclosing the body. Morgan (1982) believes that the lherzolite unit was intruded during granulite facies metamorphism of the country rocks, after the completion of tectonic deformation; the writer suggests, earlier in this report, that the harzburgite unit was emplaced only a short time after the lherzolite, i.e., during the metamorphism.

The feldspathic rocks

Age relationships

The feldspathic rocks and veins of granite material were emplaced after the harzburgite. The granitic material intrudes both the lherzolite and the harzburgite. The feldspathic rocks occur only in the harzburgite. Both have hydrated and possibly metasomatized the ultramafic body. The relationship between the granitic veins and the feldspathic rocks is not known. However, for reasons given below, it is possible that the feldspathic rocks are related to the ultramafic body. The granitic veins are probably related to a much younger period of granitic emplacement (eg. Wilson 1958).

Emplacement

The feldspathic rocks are very minor occurrences in the harzburgite, and their origin is problematical. Prider (1945) referred to andesinites within granulite facies ultramafics at Dangin as "segregations". If that is their occurrence here, they could be interpreted in one of two ways.

First, they could represent a late stage "aplitic pegmatitic" phase of the ultramafic, emplaced on primary cooling joints in the harzburgite. The feldspathic rocks contain elements (Al, Ca, Na, K, Zr), and volatiles that are incompatible with the lattice sites of orthopyroxene and olivine. Their emplacement would have been accompanied by hydration and potash metasomatism of the harzburgite.

A second view is that, petrogenitically, they are entirely unrelated to the harzburgite. Granulite facies rocks in the Western Australian wheat belt are regarded as xenolithic masses fragmented by subsequent granitoid invasion (Wilson 1958, 1959;

Prider 1945, Davidson 1968). Potash metasomatism associated with the feldspathic rocks, along with the presence of zircon, suggest that they represent a metasomatism induced by the granitoid invasion which took place about 2 800 m.y. ago (Wilson 1958).

Concluding remarks

The diamond drill cores have given us only a glimpse of what must be a complex ultramafic body. Because of extremely poor exposures in the field, really very little is known of the ultramafic-country rock relationships, or of the relationships of the consitutent members of the unltramafic body. In fact. there may well be other units in the ultramafic, besides harzburgite and lherzolite, not exposed by the drilling. Hence, any conclusions drawn from this, and the author's previous study (Morgan 1982) must be tenuous.

The relationship between the lherzolite and the harzburgite is not clear. The lherzolite, from chemical and modal evidence (Morgan 1982) appears to be a series of cumulate-rocks resulting from the differentiation of a basaltic magma. On the other hand, the slightly younger harzburgite seems to be the result of the *in situ crystallization* of an ultramafic magma. Hence, there can be no intimate petrogenic relationship between them: one is not derived from the other. Yet they are intimately related in time and space, hence they must both have been derived from the same source during the course of a continuing geological event.

One might guess that rising upper mantle temperatures resulted, first, in the generation of tholeiitic magma as a parent of the lherzolite, followed by the melting of much more refractory material, producing the harzburgite. This postulated upper mantle "hot spot" may well be the reason for the granulite facies metamorphism in the area, and could be an event in a long-continued process of sedimentation, igneous activity, tectonism, and metamorphism that was ultimately completed with the emplacement of granitoids about 2 800 m.y. ago.

References

Boyd, F. R., Fujii, T. and Danchin, R. V. (1976).—A non-inflected geotherm for the Udachnaza Kimberlite Pipe, USSR. *Yb. Carnegie Instn. Wash.,* **75**: 523-531.

Cameron, E. U. (1978).—The Lower Zone of the Eastern Bushveld Complex in the Olifants River Trough. *J. Petrol.,* **19**: 437-462.

Carswelt, D. A. and Dawson, J. B. (1970).—Garnet peridotite xenoliths in South African kimberlite pipes and their petrogenesis. *Contr. Miner. Petrol.,* **25**: 163-184.

Challis, G. A. (1965).—The origin of New Zealand ultramafic intrusions, *J. Petrol.,* **6**: 322-364.

Davidson, L. R. (1968).—Variation in ferrous iron-magnesian coefficients of metamorphic pyroxenes from Quairading, Western Australia. *Contr. Miner. Petrol.,* **19**: 238-259.

Dawson, J. B., Powell, D. G. and Reid, A. M. (1970).—Ultrabasic xenoliths and lava from the Lashuine Volcano, northern Tanzania. *J. Petrol.*, **11**: 519-548.

Deer, W. R., Howie, R. A. and Zussman, J. (1982).—*Rock-forming Minerals*, Vol. 3. (Longmans).

Frost, R. B. (1975).—Contact metamorphism of serpentinite, chloritic blackwall and rodingite at Paddy-Go-Easy Pass, Central Cascades, Washington. *J. Petrol.*, **16**: 272-313.

Green, D. H. (1964).—The petrogenesis of the high-temperature peridotite intrusion in the Lizard area, Cornwall. *J. Petrol.*, **5**: 134-188.

Hall, A. L. (1932).—The Bushveld Igneous Complex of the Central Transvaal. *Mem. Geol. Surv. S. Afr.*, No. **28**.

Hess, H. H. (1960).—Stillwater igneous complex, Montana, a quantitative mineralogical study. *Mem. Geol. Soc. Amer.*, **80**.

Hewins, R. H. (1975).—Pyroxene geothermometry of some granulite facies rocks. *Contr. Mier. Petrol.*, **50**: 205-209.

Ito, K. and Kennedy, G. C. (1967).—Melting and phase relations in a natural peridotite to 40 kilobars. *Amer. J. Sci.*, **265**: 519-538.

Loney, R. A., Himmelberg, G. R. and Coleman, R. G. (1971).—Structure and petrology of the alpine-type peridotite at Burro Mountain, California, U.S.A. *J. Petrol.*, **12**: 245-309.

Morgan, W. R. (1982).—A layered ultramafic intrusion in granulites, near Lake Kondinin, Western Australia. *J. Roy. Soc. W.A.*, **65**: 69-85.

Nesbitt, R. W. and Sun, S. S. (1976).—Geochemistry of Archaean spinifex-textured peridotites and magnesian tholeiites. *Earth Planet. Sci.: Letters*, **31**: 433-453.

Prider, R. T. (1945).—Charnockitic and related cordierite-bearing rocks from Dangin, Western Australia. *Geol. Mag.*, **82**: 145-172.

Wilson, A. F. (1958).—Advances in the knowledges of the structures and petrology of the Precambrian rocks of south-western Australia. *J. Roy. Soc. W.A.*, **41**: 57-83.

Wilson, A. F. (1959).—The Charnockitic rocks of Australia. *Geologische*, **47**: 491-510.

Vegetation of Yule Brook Reserve near Perth, Western Australia

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Abstract

The Yule Brook reserve is a small block located 20 km S.E. from Perth (32°S 115°W) in a climate of cool wet winters and hot dry summers. A clay flat is crossed by two parallel sand ridges.

The vegetation of the deep leached sand of the ridges is Banksia woodland on the crests with low shrub undergrowth continued on the treeless slopes.

The clay flats which have a shallow cover of sand and are waterlogged in winter and baked hard and dry in summer have a perennial cover of the rush type *Leptocarpus* interrupted by scattered low shrub mounds and saline depressions.

Slightly raised sections which still have some waterlogging in winter are dominated by the shrub *Leptospermum* or the conifer *Actinostrobus* in each case with a varied understorey of sedges and shrubs, semishrubs and herbs.

As a result of the extreme contrasts between the conditions in winter and summer the herbaceous flora is markedly seasonal with numerous geophytes and ephemerals. Of special interest are the many insectivorous plants *Drosera, Byblis, Utricularia* and *Polypompholyx*, and the "Trigger plants" *Stylidium* spp.

Altogether there are at least 370 indigenous species on the block, a large number for a block of less than 50 ha.

Introduction

The Yule Brook Reserve lies 20 km southeast from the centre of Perth (32°S 115°E) in a region of poorly-drained flats on the coastal plain at the foot of the Darling Scarp. One area of these flats, near Kenwick, has long been a favourite haunt of botanists because of the rich variety of unusual plant species found there. The former Government Botanist, the late Mr. C. A. Gardner for example, collected extensively in the region and Lloyd (1942), in his classic monograph on carnivorous plants, refers to it.

In 1949 the University of Western Australia purchased 34.6 ha of the "swamp region" for research and teaching purposes by members of its Botany Department. Known officially as the "Yule Brook Botany Reserve, Kenwick", but more commonly referred to by local botanists as "Cannington Swamp", the Reserve is listed in the Western Australian Government Gazette (9th November, 1979) because of its special nature. Consequently, no development of the Reserve is permitted without the approval of the Metropolitan Regional Planning Authority in addition to that of the local authority, the Gosnells City Council. The site is important as a remnant of natural swamp vegetation which is rapidly diminishing with urbanisation of the region.

The major portion of the Yule Brook Reserve was described and mapped and contoured in 1950 by the late Dr. N. H. Speck as part of a M.Sc. thesis (Speck 1952). Although his maps and descriptions of the plant communities are frequently used by staff and students of the Botany Department his work remains largely unpublished.

Since the original mapping, roads have been built (in 1961 and later) on two sides of the block, formerly only accessible from an early pipeline track (Bickley Road) along the south-western boundary. Drainage along the road verges, damage in the course of road building, and firebreaks put down and maintained since 1964 have somewhat reduced the communities mapped by Speck. Fires have been frequent and their impact is described in a second paper (Baird in prep.).

This general account of the vegetation is based primarily on Speck's work with some later observations. It is hoped that the paper will provide a background against which future changes can be assessed. A species list has been revised to incorporate some additions and many recent changes in nomenclature.

General Features of the Reserve

The Reserve site is distinctive within the general area of the swampy flats in that the flats are crossed diagonally by two parallel north-south sand ridges, the larger eastern one rising to 5-6 m above the flat while the smaller western one, which does not reach the north-west boundary, is less than 2 m. Both ridges rise steeply on the western side with a long, gradual slope to the east.
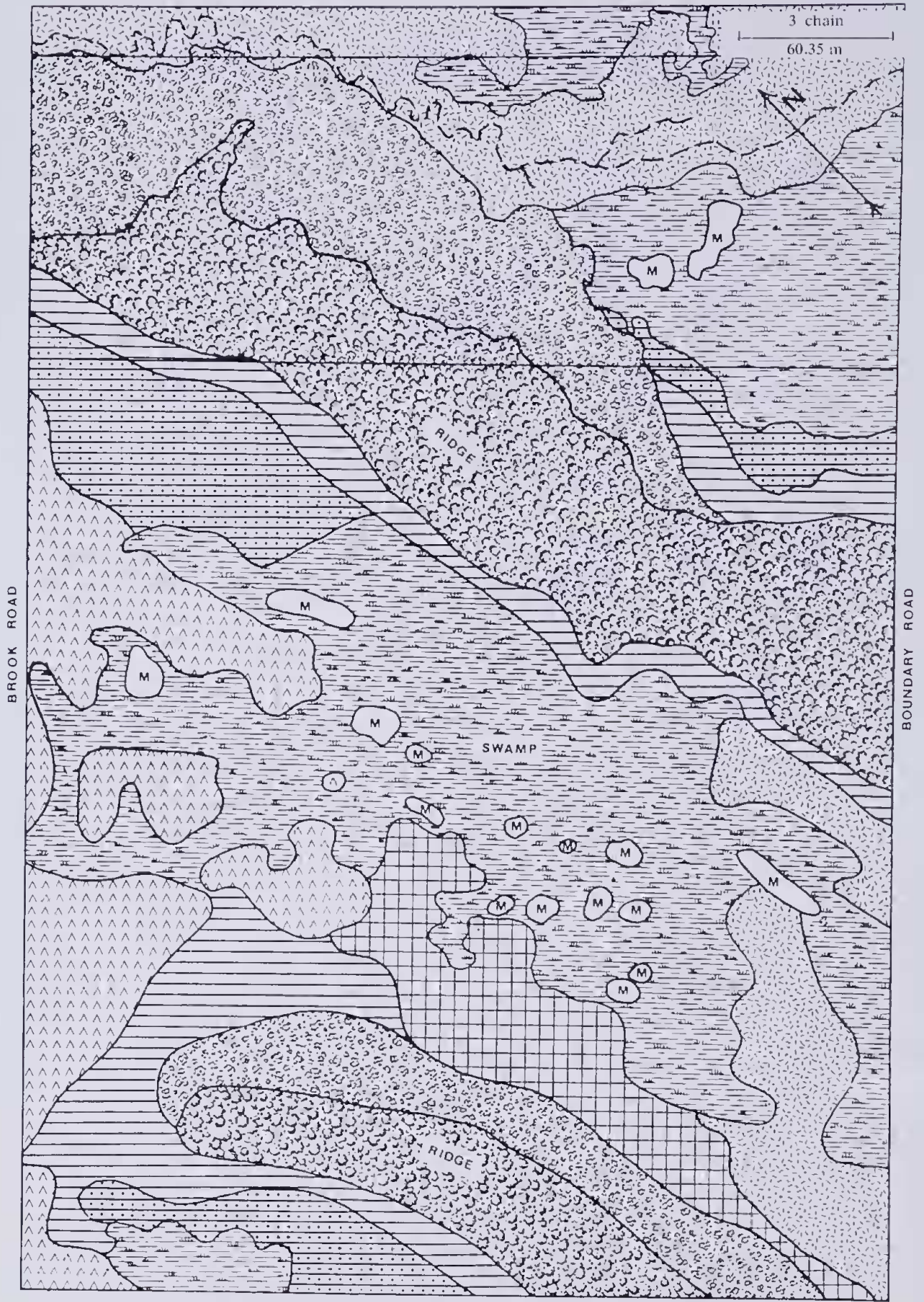
FIG 1 VEGETATION OF THE RESERVE (as mapped by N.H. SPECK 1950)

Leptocarpus flat

Leptospermum — Restio

Leptospermum mixed scrub

Actinostrobus scrub

Mixed scrub

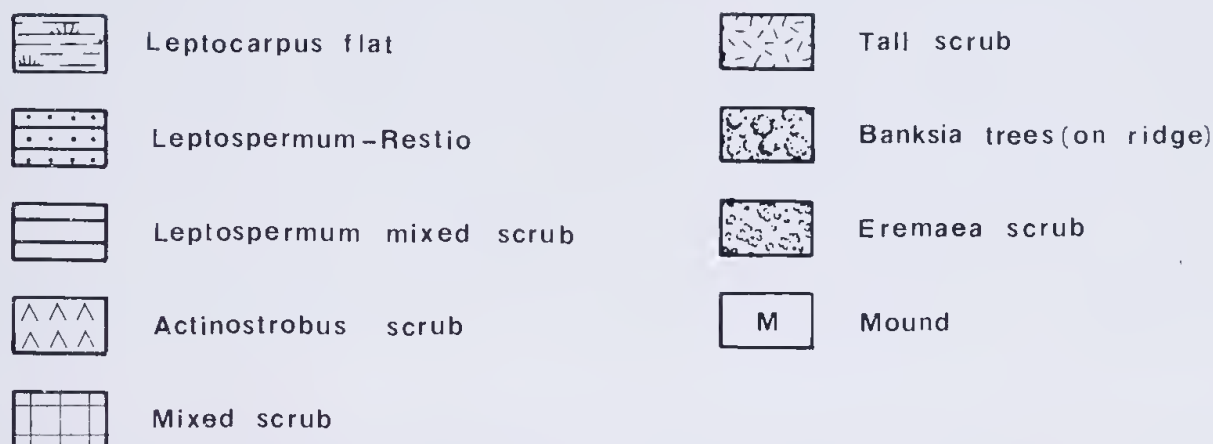Tall scrub

Banksia trees (on ridge)

Eremaea scrub

M Mound

Figure 1.—Map of plant communities. This shows the communities recognised and mapped by N. H. Speck. The outlines were copied from his M.Sc. thesis 1952 with an extension at the north eastern end.

Drainage east of the main ridge is into a small tributary of Yule Brook, but over the main flat is very sluggish so that water lies on the surface for much of the winter. A poorly-defined drainage line meanders to the west.

There is evidence from a series of straight parallel lines on aerial photographs that a portion of the flat adjacent to the eastern ridge had once been cleared and cultivated—the spacing suggests viticulture, although this is unconfirmed. It has been known in its present uncultivated state since early in this century.

The soils are strongly-leached, whitish-grey siliceous sands overlying an undulating heavy yellowish clay. On the flats the sand varies between 10-45 cm, whereas on the ridges it may be several metres deep. In parts of the flats, calcareous particles occur in the subsoil, and some low lying parts are markedly saline. In sections at the foot of the ridges a greater organic content in the wet soil produces a humus podsol and at some lower levels of the ridges an accumulation of brown iron leachate known locally as 'coffee rock' occurs at the interface between sand and clay. Details of soil profiles are given in Appendix 1.

The climate is that of the Perth metropolitan region, i.e. one of cool, wet winters and long, hot, dry summers. Of the average annual rainfall of 883 mm, 70% falls in the four winter months May-August, and only 5% in the four summer months December-March. Conditions are made more extreme on the flats by waterlogging in winter and exposure to hot drying winds in summer.

The Plant Communities

There is a clear distinction between the wooded crests and shrub covered slopes of the well drained sand ridges and the predominantly rush covered flats, which are waterlogged in winter and have a rich ephemeral flora, most conspicuous as the water recedes in spring and early summer. Intermediate levels are complex and less readily classified. Figure 2 shows general views of the reserve.

Speck in 1949-50 mapped about two thirds of the area on a chain* square grid. His map is reproduced in Fig. 1. The map has been extended to include the remainder by sketching in approximately the most obvious boundaries using aerial photographs.

For the purposes of mapping, Speck was able to identify and delimit communities as listed below:—

on the flats

Leptocarpus aristatus meadow

Leptospermum ellipticum—Restio tremulus low scrub

Leptospermum ellipticum mixed scrub

Actinostrobus mixed tall scrub

on the ridges

Banksia low scrub woodland

Eremaea low scrub

The following description uses these community names even though they may not be consistent with later terminology (e.g. Specht 1970). The photographs have been selected to show samples of the communities shown on Speck's map (Fig. 1) which should be referred to.

The Leptocarpus aristatus meadow

The species is clearly dominant and in its best development forms a dense uniform sward up to 35 cm high with a distinctive pinkish brown colour given by the persistent flowering heads. It occurs on the flats between and beyond the ridges. The section on the western first flat on the map is small but it is cut off from the major part of this sward (Fig. 2A) by the long established Bickley Road. On the third flat to the south east of the higher eastern ridge the *Leptocarpus* occurs mostly as isolated tufts on bare white sand (Fig. 6B).

* 1 chain = 22 yards = 20.2048 metres; the chain was a standard surveyor's measure.

Figure 2.—Vegetation of the flats. A. *Leptocarpus* sward looking east to Darling scarp in background, August 1957. B. View across main flat to ridge. June 1970. Flat had been burnt in 1967. C. Part of the flat with numerous small bushes of *Banksia telmatiaea* and *Calothamnus villosus*. September 1955. D. A spreading bush of *Calothamnus villosus*. E. Flat at foot of ridge, depression with black mud and ephemerals in foreground, low mounds left and right, a tall paperbark *Melaleuca* (*M. preissiana*) on edge of ridge. September 1956. F. A broad spreading mound with central *Actinostrobus*, saline depression with *Halosarcia halocnemoides* right foreground. October 1959. G. Close to the tall *Melaleuca preissiana* in figure B, *Leptocarpus* flat and shrub covered slope to woodland, *Banksia littoralis* left skyline. September 1955. H. Looking along the flat where a scraped firebreak was put down in 1964 providing deeper water and a raised sandy rim; *Utricularia inaequalis* in water *Tribonanthes* on sand *Drosera gigantea* right hand corner. October 1965.

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The most extensive area of flat lies between the two ridges (Fig. 2B). The sward of *Leptocarpus* is interrupted by an occasional isolated shrub of *Hakea varia*, *Melaleuca bracteosa* (*M. fasciculiflora*) or *Calothamnus villosus* (Fig. 2D). In places nearer the ridge, shrubs, including *Banksia telmatiaea* (*B. sphaerocarpa*) are more abundant (Fig. 2C). In some depressed parts *Leptocarpus canus* (Fig. 4E) replaces *Leptocarpus aristatus*.

Scattered unevenly through the flats are mounds (Fig. 2 E and F) which are initiated by the accumulation of drifting sand against low spreading *Melaleuca bracteosa* bushes. The mounds vary from a single shrub with a few small associates to extensive mounds with an assortment of other shrubs surrounding the *Melaleuca* and sometimes including a tall *Actinostrobus* (Fig. 2F).

Saline depressions with *Halosarcia* (*Arthrocnemum*) *halocnemoides* (Fig. 2F) throughout the flats. Small depressions may have only a single plant, larger ones a group of the samphires, in some cases with a fringe of *Selenothamnus* (*Plagianthus*) *squamatus* a species slightly less salt tolerant than *Halosarcia*.

A small colony of *Wilsonia backhousei*, occurs in a wet saline depression on the south eastern extension of the reserve.

The soil of the *Leptocarpus* flats consists of heavy domed clay covered by white sand of varying depth. (Fig. 3 and Profile appendix I.) This is a habitat of extremes. Water lies on the surface of the flats through much of the winter and gradually evaporates through spring and early summer. In summer the flats are hot and dry and windswept, consequently the herbaceous flora is markedly seasonal.

From soon after the first rains some species can be found growing and flowering, e.g. *Drosera bulbosa* in May. *Utricularia menziesii*, a tiny rosette perennial with a single long-tubed scarlet flower, *Drosera heterophylla* and the sweet scented orchid *Thelymitra antennifera* are blooming through winter on the open flats. Where water is deeper *Polypompholyx multifidia* (Fig. 4A) and the smaller and less common *P. tenellus* and *Utricularia violacea* are in flower between August and October and slightly later the purple *Utricularia hookeri*. This species is most abundant at the western foot of the ridges where seepage from the sandy slope provides longer lasting water. It is associated here with the branched sundew *Drosera gigantea* (Fig. 4B). A graded firebreak (Fig. 2H) cut through this zone in 1964 provided a new habitat for the *Utricularia*.

The peak flowering period for herbaceous geophytes occurs through August-September with *Tribonanthes variabilis* (Fig. 4C), *Burchardia multiflora*, and many orchids (e.g. *Diuris* spp.) and sundews (*Drosera* spp.) conspicuous. Also flowering in spring are the "ephemeral geophytes" such as *Utricularia menziesii*, *Drosera palaecea*, *Stylidium pulchellum* and the lycopod *Phylloglossum drummondii*. The fringes of the mounds provide a particularly favourable habitat for many of the herbaceous species.

Figure 3.—A spadeful of soil from the main flat showing the clear boundary between the sand and the underlying domed clay. May 1967. The flat had been burnt January 1967.

Most of the common annuals flower later than the perennials, usually in October-November. Members of the Asteraceae e.g. *Brachycome pusilla* (Fig. 4E) *Angianthus* spp., (Fig. 4D, F) and many small ephemerals flower over a short period and die away as the surface soil dries out. Among the most abundant of these species is the inconspicuous *Centolepis aristatus*, but species of *Hydrocotyle*, *Calandrinia*, *Aphelia* and tiny annual species of *Stylidium* are also common. The black surface of saline depressions is often densely covered with *Angianthus strictus* (Fig. 4F).

Over the summer the flats are bare of herbaceous plants, and where the *Leptocarpus* cover is sparse (or absent) the sand is moved by small "willy willies", airwhirls which tend to remove loose sand from the bare areas and pile it up against the mounds.

It is probable that these flats, although remaining basically stable show a good deal of instability in surface detail. Slight changes in drainage or
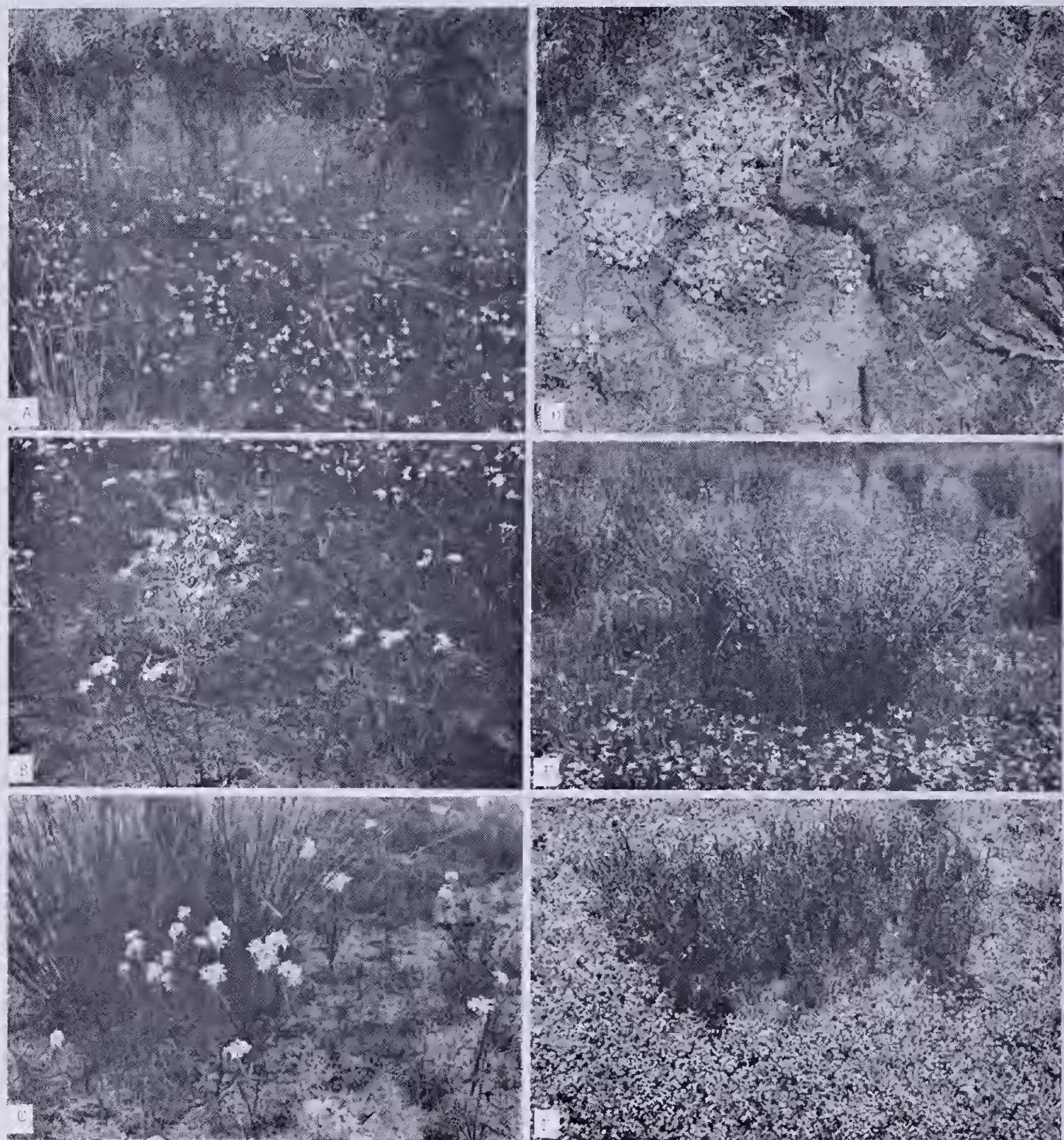
Figure 4.—Herbs of the flats. A. *Polypompholyx multifida* in flower in water. September 1965. B. *Drosera gigantea* in flower. C. *Tribonanthes variabilis* in front of a clump of *Gahnia trifida*. D. *Angianthus humifusus*. December 1st 1964. E. *Brachycombe pusilla* in front of clumps of *Leptocarpus canus*. October 29th 1975. F. Dense cover of *Angianthus strictus* in a saline depression with *Halosarcia halocnemoides*. October 29th 1975.

differences in annual rainfall in different years may vary the distribution and abundance of annual species. For example in the particularly dry year of 1959 no *Utricularia hookeri* was found in flower although it was present in its usual profusion in the following year. Loneragan (1973) has demonstrated marked fluctuations in numbers and distribution pattern of the geophyte *Tribonanthes variabilis*.

At the intermediate levels between the waterlogged flats and the sandy ridges the vegetation is perhaps at its richest and most varied, but it is also more difficult to classify. Speck recognised three communities:

Leptospermum ellipticum—Restio tremulus low scrub

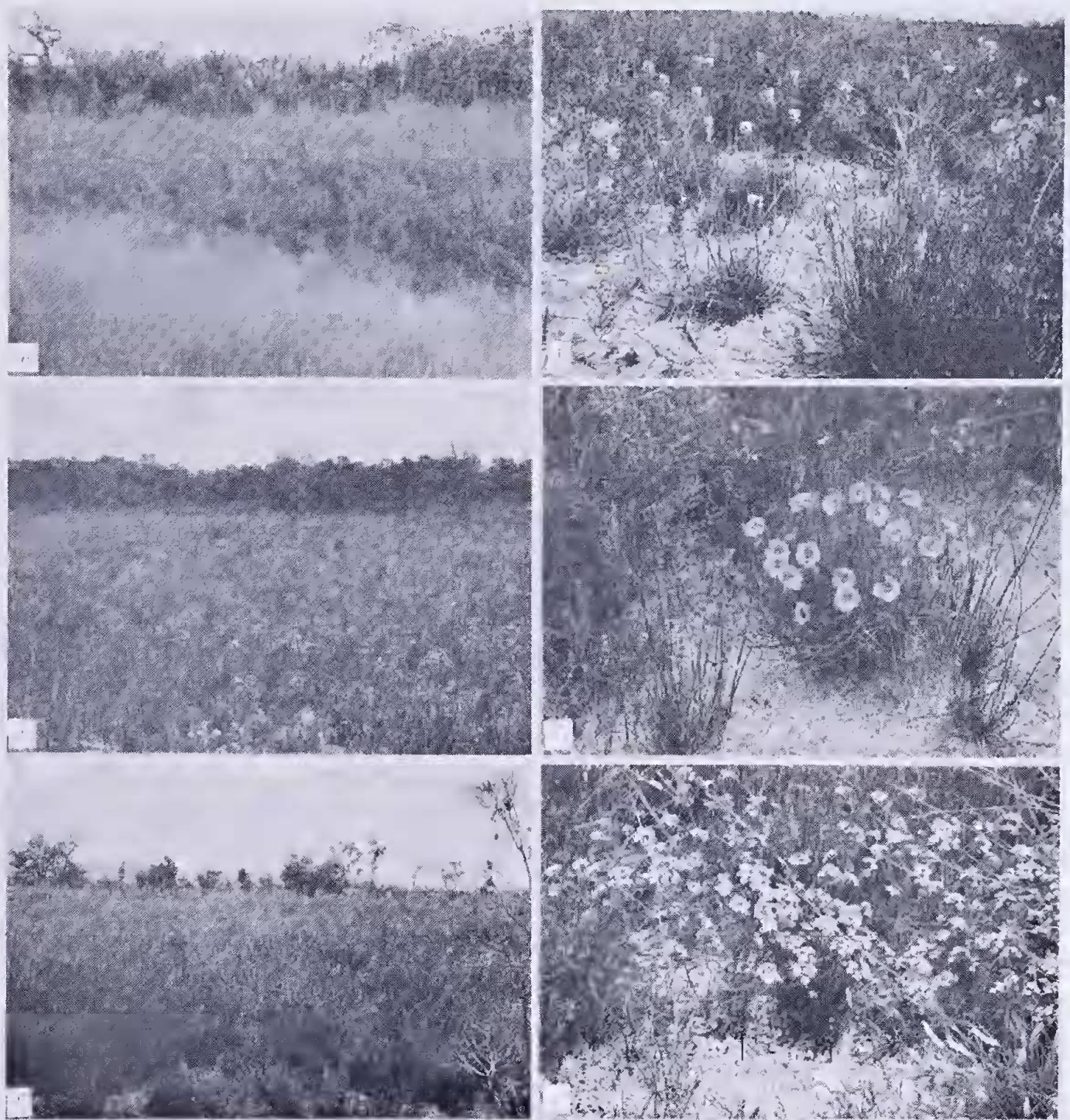*Leptospermum ellipticum* mixed scrub

Actinostrobus tall scrub

Figure 5.—*Leptospermum* communities. A. Narrow zone of *Leptospermum ellipticum* on the steep western slope of the eastern ridge, *Leptocarpus* sward in foreground, *Adenanthos* shrubs behind *Leptospermum*, *Nuytsia* projecting on left skyline. October 31st 1968. B. Broad zone of *Restio* and *Leptospermum* (in flower) eastern slope, *Banksia* woodland in background. October 31st 1968. C. Very gradual slope up to northern end of low western ridge. Dense low scrub of *Restio*, *Leptospermum*, *Banksia telmatiaea*, *Nuytsia floribunda* and slender *Eucalyptus calophylla* on the skyline. *Leptocarpus* in foreground. October 1965. D. *Conospermum huegelii* in flower on firebreak, dense mixed scrub behind. September 18th 1977. E. *Byblis gigantea* in flower. November 5th 1970. F. *Lechenaultia expansa* in flower, *Johnsonia* sp. left corner. October 31st 1968.

Leptospermum ellipticum—Restio tremulus low scrub

This is a clearly defined community with usually a sharp boundary where adjacent to the *Leptocarpus* meadow (Fig. 5A) made even more conspicuous when the *Leptospermum* is in flower. The two species *Leptospermum* and *Restio* are codominant although in old stands the *Leptospermum* may grow above and conceal the *Restio* (Fig. 5A).

Where the ridge rises steeply on the western slopes there is a narrow zone of *Leptospermum-Restio* with an upper rim of *Leptospermum* without *Restio* (Fig. 5A); where, as towards the northern end of both ridges, there is a fairly extensive shelf just above the main level of the flat but still waterlogged in winter a wide *Leptospermum-Restio* (Fig. 5B) community is particularly rich, with a

great variety of other swamp tolerant species. Common shrub species included are *Banksia telmatiaea*, *Hakea ceratophylla*, *H. sulcata*, *Calothamnus villosus*, the semishrubs *Conospermum huegelii* (Fig. 5D), *Conostylis filifolius*, *Leschenaul ia expansa* (Fig. 5F), *Petrophile longifolia* and many different sedges and rushes, for example, *Cyathochaeta avenacea*, *Schoenus* spp.. and *Anarthria gracilis*.

The seasonal herbaceous flora is again rich and varied with the insectivorous *Byblis gigantea* (Fig. 5E) and *Drosera neesii* common, with *Anigozanthos viridis*, *Stylidium* spp. and many of the herbs of the *Leptocarpus* flats previously listed.

Compared to the soils of the flats, the soil here contains a greater quantity of organic matter and is more a humus podsol with a tendency to coffee rock formation (see profile B west of first ridge and profile 2 west of main ridge, Appendix 1.).
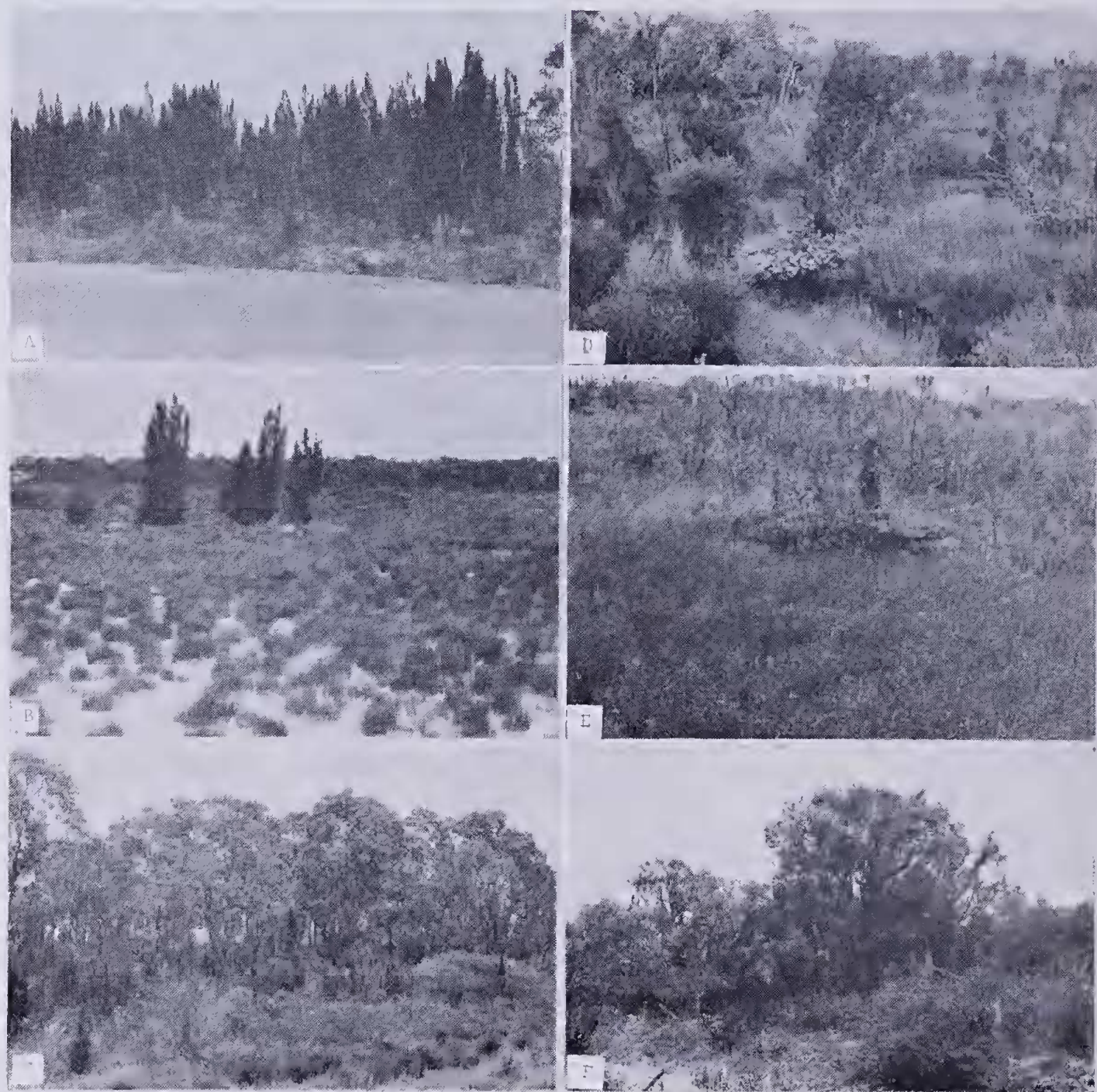

Figure 6.—*Actinostrobus* and other tall shrubs. A. A long unburnt stand of *Actinostrobus pyramidalis* outside the Reserve, November 1971. B. Tall *Actinostrobus* on the edge of the rise from the 3rd flat, *Leptocarpus* in foreground. October 1968. C. Young *Actinostrobus* growing under a stand of marri adjacent to the *Actinostrobus* of A. D. A mixed wet area. *Actinostrobus* centre, *Leptocarpus canus* foreground, *Viminaria* background right, *Melaleuca* background left. 23rd August 1956. E. Corner of the western flat, *Leptocarpus aristatus* foreground, prostrate *Calothamnus* with erect young *Actinostrobus*, *Viminaria* background. 9th December 1969. F. *Melaleuca rhaphiophylla* in flower on edge or creek, eastern boundary of reserve. 31st October 1968.

Leptospermum ellipticum mixed scrub

As the ground slopes up onto the ridge the *Leptospermum* increases in height, *Restio* gradually disappears, and new species appear with many of those from the lower zone. In Speck's description, "there is no sharp floristic boundary between the two *Leptospermum* zones, the change is one of structure; on the better drained and rising ground the *Leptospermum* increases to almost twice its height in the lower one and this is also true for other species." The mixed *Leptospermum* scrub grades from the lower *Leptospermum-Restio* and it is only where the changes in slope are sudden that a definite boundary can be recognised. Nevertheless, there is on both sides of the ridges this zone of dense scrub of variable composition but containing species which do not occur further up the ridges. The more abundant shrubs here include *Banksia telmatiaea, Beaufortia squarrosa, Daviesia incrassata, Euchilopsis linearis* and *Hypocalymma angustifolium,* and in some parts, *Astartea fascicularis* or *Regelia ciliata.* Of these species *Banksia telmatiaea* (Fig. 7C) has a greater vertical range than most, extending from the *Leptocarpus* flats to beyond the uppermost *Leptospermum.* A few specimens of *Melaleuca preissiana* (old man paperbark, Fig., 2G) and *Banksia littoralis* (swamp banksia) also occur at this level and, although this is not its best habitat, several small trees of *Eucalyptus calophylla* (marri) (Figs. 2H, 6C). In the long unburnt southeastern slope of the main ridge this scrub developed into a dense thicket 1.5-2.0 m tall with *Banksia telmatiaea, Beaufortia squarrosa, Daviesia incrassata* and *Hakea varia* as the principle components.

The soil, as for the lower zone, is a humus podsol but as this zone is higher up the ridge than the *Leptospermum-Restio,* the sand is deeper above the water level. The coffee rock layer is better developed here than in any other soil of the reserve (profile C, Appendix 1).

Mixed low scrub

Towards the south eastern section at the foot of the low ridge the Leptospermum dominated community of the northwestern end is replaced by a mixed assemblage of low shrubs in which the mound building *Melaleuca bracteosa* is conspicuous with *Hakea varia, Banksia telmatiaea, Verticordia spp.* and other shrubs and herbs some indicating lime in the soil eg. *Grevillea thelemanniana* and *Acanthocarpus. Acacia lasiantha* is abundant, particularly after fires. All these plants belong to species present in adjacent communities, but form a somewhat distinct grouping. Speck outlined the area on the map as mixed low scrub.

Actinostrobus pyramidalis tall scrub

Because of the characteristic conifer habit and dark foliage *Actinostrobus* communities (Fig. 6) are easily recognised and can be mapped on the basis of the presence of the species. At its best it forms almost a miniature conifer forest with slender crowded small trees. One such stand (Fig. 6A) occurs adjacent to the reserve and, in contact with this, young plants were growing under marri (Fig. 6C). Tall plants on the edge of the eastern flat are shown in Figure 6B.

Most stands on the reserve have scattered *Actinostrobus* associated with some of the shrubs of the *Leptospermum* zones *Hypocalymma angustifolium* is particularly common, other species are *Melaleuca lateritia, Beaufortia squarrosa, Leptospermum ellipticum, Kunzea micrantha, Verticordia* spp., *Andersonia aristata, Conostylus* spp., *Restio* spp. and a wealth of seasonal herbaceous species, *Stackhousia huegelii, Philydrella pygmaea, Brachycome pusilla* (Fig 4E) and others. *Isoetes* is sometimes found growing in black mud in water filled depressions often but not invariably near *Actinostrobus* or *Viminaria.* Although *Actinostrobus* stands are at approximately the same contour level as the *Leptospermum-Restio* the soil contains less humus, and the underlying clay has a high pH and usually contains calcarous nodules.

A new road and parallel firebreak cut through the *Actinostrobus* stands on the north west side of the block have considerably reduced the area shown in Speck's map, and repeated fires have prevented the development of tall stands. Near the north-eastern corner of the reserve a few trees have escaped fire and reached an age of some 160 years as shown by ring counts (Loneragan pers. com.).

Viminaria juncea, a tall broom-like legume dominates big areas of swampy flats in the district which have clay at the surface. It has spongy pneumatophores which project up through the water covered clay from horizontal roots. On the Reserve where most of the clay is covered by sand there are no extensive suitable habitats and the occurrences are too scattered to justify separate mapping. Speck simply mentions it as occurring in some of the *Leptospermum-Restio* and *Actinostrobus* areas. It is shown in figures 6D and 6E.

Fringing thickets of tall shrubs

Dense thickets of tall shrubs, mainly species of *Melaleuca, M. rhaphiophylla* (paperbark) (Fig. 6F); *M. uncinata, M. viminea, M. cuticularis,* border the small creek (more a swamp at its southern end) on the eastern boundary of the reserve. Another group of paperbarks occurs along a drainage line in the south western extension across Bickley Road and there is a deeper paperbark swamp near the corner of Bickley and Boundary Roads in an adjacent property.

Banksia woodland

On the crest of the ridge is a low woodland (Fig. 7A, B) of *Banksia attenuata* and *Banksia menziesii* with a few trees of *Casuarina fraseriana* and still fewer of *Banksia ilicifolia.* The slope up to the dense banksias in the background is shown in Figure 7C. The undergrowth is a low shrub layer with a high percentage of harsh perennial monocotyleons. The community is representative of the vegetation of the poor leached sands of much of the coastal plain. Here as with most South-West Australian vegetation dominance of a type of small-leaved sclerophyllous shrub is the pattern rather than dominance of any one species. Common dicotyledons are *Hibbertia* spp., *Hovea trisperma, Bossiaea eriocarpa, Acacia pulchella, Jacksonia flori-*

bunda, Leucopogon spp., *Astroloma* spp., *Dampiera linearis* and many others. Common Monocotyledons are *Xanthorrhoea priessii, Conostylis* spp., *Patersonia occidentalis, Amphipogon turbinatus.* The tall grey foliaged shrub, *Adenanthos cygnorum* (Fig. 7D) in places forms a conspicuous zone fringing the

Banksias. Scattered *Nuytsia floribunda* (Christmas tree) trees occur beyond the boundaries of the Banksias on the slopes of both ridges (Figs 5A & C). The small stand of Banksia on the low western ridge was cleared illegally about 1954 and has not regenerated.
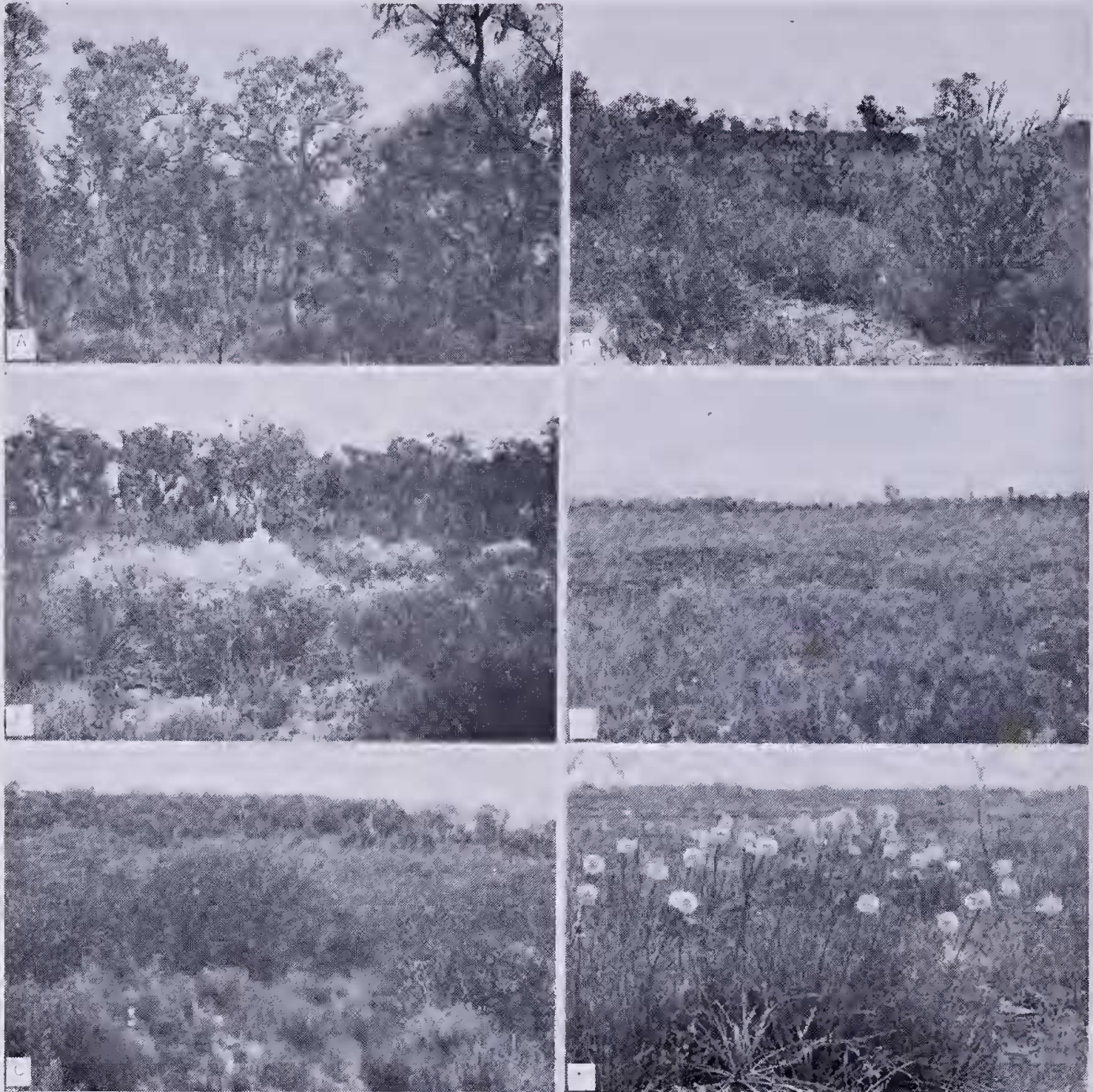
Figure 7.—Vegetation of the ridge. A. Banksia woodland on crest of ridge, *B. attenuata* centre and left edge. *B. menziesii* left of centre, *Casuarina fraseriana* overhanging right corner, low shrub undergrowth. September 19th 1977. B. *Conospermum stoechadis* in flower on eastern slope. September 19th 1977. C. Part of slope up to dense woodland, *Adenanthos* in front of Banksias, rounded bushes of *Banksia telmatiaea* on edge of slope behind *Leptocarpus.* October 29th 1975. D. Shrub cover on upper slope of ridge, *Adenanthos cygnorum* (tall shrub), *Eremaea pauciflora* low rounded shrub centre on edge of firebreak, *Xanthorrhoea* left. October 26th 1965. E. View along eastern slope of ridge with dense low shrub cover. December 9th 1969. F. *Dasypogon bromeliifolius* in flower on eastern slope of low western ridge. October 1959.

Eremaea low scrub

The shrub community of the slopes is continuous with the undergrowth of the woodland but in the open is denser with a higher proportion of larger species. *Eremaea pauciflora*, a compact spreading microphyllus shrub, is particularly conspicuous in late spring with its massed orange flowers. On the first ridge it is sufficiently abundant to justify Speck's giving its name to the community but there are many associated shrub species. The monocotyledons, *Dasypogon bromeliifolius* (Fig. 7F), *Lyginia barbata, Schoenus curvifolius, Anigozanthos humilis, Loxocarya fasciculata*, and *Calectasia cyanea* are also abundant. Since the clearing of the Banksias this low scrub continues right across the ridge.

On the extensive eastern slope of the main ridge (Fig. 7E) the shrub community is richer and more diversified and *Eremaea* though abundant is only one of several conspicuous shrubs. *Casuarina humilis* forms bulky cover in places and there is a stand of *Conospermum* sp. (Fig. 7B), very conspicuous when in flower, at a mid level on the slope. *Jacksonia floribunda* is common throughout, its flowering shoots projecting above the general level. However, the main character is the large number of species of low shrubs and semi-shrubs, and fibrous or shrubby monocotyledons. At least eighty species in these categories have been recorded on the ridges and there are also seasonal herbaceous plants.

At the northern part the slope goes down to a small creek meandering along the eastern boundary. At the southern end it goes through the series of *Leptospermum* scrubs to the third *Leptocarpus* flat (Fig. 6B).

There is a gradual change in species composition down the slopes with some not very clear zoning—for instance *Jacksonia furcellata* grows on the lower slopes of both ridges *Jacksonia floribunda* right across the upper levels. *Xanthorrhoea* is more abundant at lower levels. On the lower parts of the low ridge, *Eremaea* is replaced by another myrtaceous shrub of similar habit, *Melaleuca seriata*, before the more definite *Leptospermum zone* is reached.

Flowering on the ridges extends from soon after the first winter rains into late summer but as on the flats with a marked spring maximum. Undershrub species which have their buds formed the previous season eg. *Acacia stenoptera* and several epacrids are the first to bloom followed by *Hovea, Daviesia, Hibbertia, Bossiaea* and others some with flowering extending over several months (eg. *Hibbertia hypercoides). Eremaea, Jacksonia* and *Adenanthos* are slightly later. The tree species of Banksia supply flowers throughout the year *B. menziesii* and *B. Littoralis* autumn-winter; B. attenuata spring-summer. Flowering of seasonal herbaceous species is also spread but with each species lasting a shorter time as illustrated in the orchids. As on the flats annuals are in general later than geophytes.

Tall scrub

A strip along the southeastern side between the ridges was mapped by Speck as tall scrub but with some doubts as to its status. This is a disturbed area crossed by old tracks, with uneven ground and numerous weeds. The tall species remaining are *Kunzea vestita*, several species of *Melaleuca*, some *Actinostrobus, Adenanthos* and abundant *Acacia saligna*, a species which often increases on disturbed ground as seen also along the road-verges to the northwest of the Reserve. The profile is very uneven but some bushes reach a height of 3-4 metres.

Flora

The Flora of the sand ridges is as found in Banksia woodlands on poor leached sand in other parts of the coastal plain. It consists of representatives of the characteristics south-west families and genera, for example Proteaceae (8 spp.) Papilionaceae (10) Myrtaceae (8) Epacridaceae (8) Dilleniaceae (3) Liliaceae (6) Xanthorrhoeaceae (16) Haemodoraceae (7), orchids and a few grasses and annual composites.

The flora of the varied levels of the wet flats is much more diverse and unusual containing a large number of species of specialised wet habitats, many of exceptional botanical interest. *Actinostrobus* is an endemic W.A. conifer restricted to certain types of swamp which although widely scattered are becoming reduced by clearing. *Phylloglossum* is a highly specialised Lycopod. There are no true ferns.

Insectivorous plants are particularly well represented with five species of rooted bladderworts; three of *Utricularia* and two of *Polypompholyx; Byblis gigantea*, (rainbow plant); six species of *Drosera* (sundews) on the flats and others on the ridges. Another genus of special interest is *Stylidium* the "trigger plants" with their sensitive column involved in insect pollination. There are at least 20 species including those on the ridges.

Small geophytes and annuals belonging to many different genera and families from Centrolepidaceae to Asteraceae (Compositae) and Apiaceae (Umbelliferae) as seen in the species list are found on the flats.

As usual in swampy ground there are many sedge and rush types Cyperaceae (9-10 spp.) Restionaceae (10) and a few Juncaceae.

Among shrubs on the wet flats Myrtaceae (± 20) are numerous with ten species of *Melaleuca* and six of *Verticordia*. Proteaceae are represented by Hakea (4), Grevillea (1), Petrophile (2) and Conospermum (1) and there are several semi herbaceous Goodeniaceae.

The total indigenous flora of the reserve numbers at least 370 species in 52 families of which Dicotyledons number 39 families, 113 genera and 226 species, and Monocotyledons 13 families with 62 genera and 142 species; 1 Conifer, 1 Cycad, 3 Pteridophytes.

Aliens

Introduced plants have not been included in the species list. Many common metropolitan weeds have occurred on parts of the site since long before it was a botanical reserve. e.g. *Romulea rosea, Briza maxima* and other grasses and medics, *Ursinea anthemoides* (on the ridge) and other annuals. *Parentucellia viscosa* and *Dittrichia graveolans* are well established on the western ridge. Recently more aggressive

weeds have heen invading from the road verges: e.g. *Watsonia pyramidata, Gladiolus caryophyllaceus* and other bulbous species mainly of South African origin. The perennial veld grass *Ehrharta calycina* is a more recent invader. Monitoring the spread of weeds could be a project for the future.

Bryophytes have not been listed. This would he better done for a much wider area. The habitat of the reserve with most of the surface loose sand is unfavourable for liverworts which however do form a surface cover in parts of the regional flats where the surface is a clay loam. On the reserve there are moss cushions in the shelter of hushes on some of the old established mounds and small isolated occurences of liverworts.

Discussion

This paper gives a general idea of the topography of the reserve, types of vegetation and species present. The vegetation has been described under community types. In a situation such as this where habitat differences are marked as between well drained sandy ridges and waterlogged flats there is a distinct assemblage of species tolerant of each condition, and as the change in physical gradient is steep the ecotone is narrow. Furthermore where there are clear dominants as in the *Leptocarpus* and *Leptospermum* and *Actinostrobus* zones it is possible to draw boundaries based on the boundaries of these species, although the continuum concept may apply if all species are considered. On the long gradual slopes with many species but none clearly dominant there are slight gradients in species distribution but the same type of low shrub vegetation with many species so that the whole slope can be classed as one community.

Although the flats are clearly dominated by the *Leptocarpus* sward there is on the flats a mosaic pattern of minor species which results from small habitat d.fferences; e.g. slight difference in level, exposure of clay at the surface, amount of humus, presence of underlying calcareous nodules, and slight differences in salinity apart from the well defined saline depressions with *Halosarcia*.

Noteworthy in all of the wetlands and to a lesser extent on the sand ridges is the larger number of herbaceous geophytes including some tiny "ephemeral geophytes". In the valuable study by Pate and Dixon (1981) of the bulbous, cormous and tuberous plants of W.A. no fewer than 50 of the species occurring in the Southwest occur on the small Yule Brook Reserve. Some have been studied in detail; morphology and growth of underground organs and changes in chemical resources through the seasons, thus increasing understanding of the methods of survival and reproduction in the difficult environment.

In addition to the herbaceous geophytes there are the many wiry rhizomatous plants which do not die down in summer but have the geophyte character of protected underground growing apices.

Changes in the vegetation and habitat since 1950 are difficult to assess as no quantitative records have been kept until recently. Part of the *Actinostrobus* stands was totally removed by the road put down in 1961 and firebreaks have cut into all communities

near the boundaries and at the foot of the ridges. The effect of drains along the roads does not appear to extend far into the block. Unt.l a few wet seasons follow the long drought (1975, 6, 7) it is difficult to say whether changed drainage or drought is responsible for the flats being drier and more saline than previously remembered. It remains to be seen whether this is continuing or reversible.

An invasion by aggressive weeds from road verges is an obvious change, and with increased traffic, including earth carrying trucks, the chances of fresh introductions are increasing.

The influence of fire will be discussed in a second paper.

The site has a long history of involvement in botanical studies: taxonomic collections and descriptions over many years by government botanists and others and specialised studies such as *Actinostrobus* Saxton 1913, Baird 1937) insectivorous plants (Lloyd 1942), *Phylloglossum* (Hackney 1950), and recently *Viminaria, Cyathochaeta, Hakea sulcata* (Lamont 1972, 1974, 1976), *Tribonathes* (Loneragan 1973), Pate and Dixon 1981, Goble-Garrett, Bell and Loneragan 1981). Many detailed studies are in progress and the reserve should provide research opportunities for many years. The fact that it is close to the city makes it particularly useful for student work and it is hoped that any deterioration of the site will continue to be slow as it appears to have been to date.

References

Baird, A. M. (1937).—The supensor and emhryo of *Actinostrobus. J. Roy. Soc. of W.A., 23:*

Erickson, R. (1958).—Trigger Plants. Lamh Paterson Pty. Ltd.

Erickson, R. (1968).—Plants of Prey. Lamb Paterson Pty. Ltd.

Goble-Garratt, E. M., Bell, D. T., Loneragan, W. A. (1981).— Floristic and leaf structure patterns along a shallow elevational gradient. *Aust. J. Bot.* **29:**

Grieve, B. J. and Blackall, W. E. (1965 pt III, 1975 pt IV).—How to know Western Australian Wildflowers. University of W.A. Press.

Green, J. W. (1981).—Census of the Vascular Plants of W.A., W.A. Herharium.

Hackney, F. M. V. (1950).—A review of and contribution to the knowledge of *Phylloglossum drummondii* Kunze. *Proc. Linn. Soc. N.S.W.,* **LXXV:**

Lamont, B. (1972).—Proteoid roots in the legume *Viminaria juncea. Search,* 3:

Lamont, B. (1974).—The biology of dauciform roots in the sedge *Cyanthochaetae avenacea. New Phytol.,* **73:**

Lamont, B. (1980).—Blue green algae in nectar of *Banksia* aff. *sphaerocarpa. W.A. Naturalist,* 14: 193-4.

Lloyd, F. E. (1942).—The Carnivorous Plants. Chronica Botanica.

Loneragan, W. A. (1973).—Change in pattern of plant distribution on Cannington Swamp, Cannington, Western Australia. 45th ANZAAS Congress Perth, August 1973, Section 12 Abstracts, p. 70.

Pate, J. S. and Dixon, K. W. (1981).—Plants with fleshy underground storage organs—a Western Australian survey. In "Biology of Australian Plants" ed. J. S. Pate and A. J. McComb. University of W.A. Press.

Saxton, W. J. (1913).—Contributions to the life history of *Actinostrobus pyramidalis. Ann. Bot.*, **XXVII**:

Smith, G. G. (1980).—Rushes, Sedges and Reeds. *W.A. Naturalist, 14*:

Speck, N. H. (1952).—The ecology of the metropolitan sector of the Swan Coastal Plain. M.Sc. thesis University of W.A.

Appendix I

Soil Profiles of Yule Brook Reserve

Note:—Profiles 1-4 were taken by W. M. McArthur in 1981 on the central swamp flat, adjacent slightly raised areas and on the main sand ridge, all towards the north western side of the block.
Profiles A-F are from N. H. Speck's thesis and were taken in 1950 in a series from the swamp flat at Bickley road to the top and eastern slope of the low sand ridge.

1. *Leptocarpus* Zone

Flat landscape with evidence of salt (NaCl) on the surface and a Solonetz profile (or a strong texture-contrast profile).

0-5 cm	Grey-brown coarse sand.
5-40 cm	Very light grey coarse sand.
40-60 cm	Dull olive brown sandy clay with faint greenish-grey moles. The clay is markedly domed with organic staining on the surface of the domes. Some ferruginous concretions (0.5 cm diam).
60 cm	Ferruginous hard pan.

2. *Leptospermum Zone* Flat landscape

Soil profile is a *humus podzol* with following description:—

0-5 cm	Dark grey-brown coarse sand.
5-30 cm	Light grey coarse sand.
30-60 cm	Very light grey-brown coarse sand.
60 cm	Black indurated organic pan.

3. *Banksia Community on Main Sand Ridge*

The soil is composed of almost white coarse silicious sand which shows no profile differentiation other than organic staining in the surface. The sand may he 6 m deep overlying a clay substrate. There is a surface layer of decomposing organic matter. The profile on the treeless lower slopes of the ridge is similar but is not so deep.

4. *Actinostrobus* Zone

Flat or slightly hummocky landscape, slightly elevated above the *Leptocarpus* Zone—and with a Solonetzic Profile.

0-5 cm	Grey coarse sand.
5-70 cm	Very light grey sand.
70-100 cm	Yellow brown to greenish mottled sandy clay.
100-120 cm	Olive brown sandy clay with soft lime and some limestone nodules pH 8.0.

Profile A. *Leptocarpus aristatus* community on first flat.

Horizon	Depth (cm)	General Description
A0	—	Very little litter.
A1	2-8	Light grey with little organic material pH 7.0.
A2	8-12	Very light grey sand—showing signs of leaching.
	12-35	Very leached white sand.
B	35	Dull yellow sandy clay.
	60-75	Black, gritty nodules appear in the clay.
	75-100	Clay becomes purer and deep yellow.
	100-150	Very sticky bright yellow and blue mottled clay.
	165	Calcareous particles pH 9.0.

Profile B. *Leptospermum-Restio community* at base of first rise.

Horizon	Depth (cm)	General Description
A0		Considerable litter.
A1	0-15	Very dark grey sand, black when wet and considerable organic matter pH 5.
	15-60	Leached light grey sand
B1	60	Sand begins to darken and develops rapidly into a brownish hardpan.
	75-90	Dark brown coffee rock—but is very clayey. Shows definite columnar jointing during the summer.
	90-165	Clay of a light brown colour and with a few black nodules (as similar horizon in Profile A).
	170	Hard white layer of calcareous material pH 8.

Profile C. *Leptospermum-Banksia sphaerocarpa* Community.

Horizon	Depth (cm)	General Description
A0		Abundant litter.
A1	0-12	Very dark grey sand, black if wet; contains abundant organic matter pH 5.0.
	12-20	Light grey sand showing signs of leaching.
	20-90	Leached grey-white sand.
	90+	Very thick hard dark brown coffee rock pH 4.5.

Profile D. Banksia Low Scrub Woodland Community; on first ridge.

Horizon	Depth (cm)	General Description
A0		Very little litter.
A1	0-8	Grey sand with little organic matter pH 5.3.
	8-20	Light grey sand—becoming leached.
	20-152	Very leached white sand.
	152-177	Definately darkened layer of brown sand, which suggests slight tendency to form coffee rock.
	177-200	Yellow-hrown clay streaked with blue at depth pH 5.2.

Profile E. *Eremaea Low* Scrub: first ridge.

Horizon	Depth (cm)	General Description
A0		Little litter.
A1	0-8	Mid-dark grey sand. pH 5.4.
	8-30	Light grey sand—showing transition to leached sand.
	30-165	Leached light grey to white sand.
	165-170	A dark brown layer of poorly formed coffee rock.
	170-180+	Brown-yellow clay. pH 5.3.

Profile F. *Actinostrobus* Community: along weak drainage line.

Horizon	Depth (cm)	General Description
A0		No litter.
A1	0-2.5	Very dark sedimentary layer—this is very low lying—represents a part of the very poorly defined drainage channel. pH 6.5.
	2.5-10	Grey sand, rapidly showing signs of leaching.
	10-35	White leached sand.
	35-60	Yellow-brown clay. pH 7.0.

Appendix II

Species List—Yule Brook Reserve

Note—Names in brackets are the names by which the species was formerly known.

PTERIDOPHYTA:

    LYCOPODIACEAE:

        Phylloglossum drummondii Kunze

    SELAGINELLACEAE:

        Selaginella gracillima (Kunze) Alston

    ISOETACEAE:

        Isoetes drummondii R.Br.

GYMNOSPERMAE:

    ZAMIACEAEA:

        Macrozamia riedlei (Gaud.) Gardn.

    CUPRESSACEAE:

        Actinostrobus pyramidalis Miq.

ANGIOSPERMAE—MONOCOTYLEDONEAE:

    CENTROLEPIDACEAE:

        Aphelia cyperoides R.Br.
        A. drummondii (Hieron.) Benth.
        Centrolepis aristata (R.Br.) Roem et Schultes
        C. glabra (F. Muell.) Hieron.
        C. humilliuma (F. Muell.) Benth.
        C. polygyna (R.Br.) Hieron.
        Desvauxia drummondiana Nees (*C. drummondii* (Nees) Hieron).

CYPERACEAE:

Cyathochaeta avanacea (R.Br.) Benth.
Cyperus tenellus L.f.
Gahnia trifida Labill.
Isolepis marginata (Thunb) A.Dietr. (*Scirpus ant-urcticus* L.)
Lepidosperma angustatum R.Br.
L. resinosum (Nees) Benth.
Mesomelaena stygia (R.Br.) Nees
M. tetragona (R.Br.) Benth.
Schoenus andrewsii W.V. Fitzg.
S. asperocarpus F. Muell.
S. benthami F. Muell.
S. brevifolius R.Br.
S. curvifolius (R.Br.) Benth.
S. jamesonianus W.V. Fitzg.
S. nanus (Nees) Benth.
S. pedicellatus (R.Br.) Benth.
S. rigens (S.T.) Blake.
S. trachycarpus F. Muell.
Tetrariapsis octandra (Nees) Kuekenthal

HAEMODORACEAE:

Anigozanthos bicolor Endl.
A. humilis Lindl.
A. manglesii D. Don
A. viridis Endl.
Conostylis aculeata R.Br. ssp *preissii* (Endl.) J. W. Green
C. aurea Lindl.
C. candicans Endl.
C. filifolia F. Muell.
C. juncea Endl. (*C. involucrata* Endl.)
C. setigera R.Br.
Haemodorum brevisepalum Lindl.
H. paniculatum Lindl.
H. simplex Lindl.
H. spicatum Rr.Br.
Phlebocarya ciliata R.Br.
Tribonanthes brachypetala Lindl.
T. uniflora Lindl.
T. variabilis Lindl.

HYPOXIDACEAE:

Hypoxis occidentalis

IRIDACEAE:

Orthrosanthus laxus (Endl.) Benth.
Patersonia juncea Lindl.
P. occidentalis R.Br.
P. umbrosa Endl.

JUNCACEAE:

Juncus bufonius L.
J. capitatus Weig.
J. pallidus R.Br.

JUNCAGINACEAE:

Triglochin calcitrapa Hook.
T. centrocarpa Hook.
T. minutissima F. Muell.
T. mucronata R.Br.
T. procera R.Br.
T. stowardii N. E. Brown

LILIACEAE:

Agrostocrinum scabrum (R.Br.) Baill.
Arnocrinum preissii Lehm.
Arthropodium preissii Endl.
Borya scirpoidea Lindl.
Burchardia multiflora Lindl.
B. umbellata R.Br.
Burchardia sp.
Chamaescilla corymbosa (R.Br.) F. Muell.
Johnsonia lupulina R.Br.
J. pubescens Lindl.
Laxmannia ramosa Lindl.
L. sessiflora Dcne.
L. squarrosa Lindl.
Sowerbaea laxiflora Lindl.
Thysanotus dichotomus (Labill.) R.Br.
T. multiflorus R.Br.
T. patersonii R.Br.
T. scaber Endl.
T. sparteus Lindl.
T. thyrsoideus Baker
T. triandrus (Labill.) R.Br.
Wurmbea dioica (R.Br.) F. Muell.

ORCHIDACEAE:

Caladenia deformis R.Br.
C. discoidea Lindl.
C. flava R.Br.
C. gemmata Lindl.
C. hirta Lindl.
C. huegelii Reichb. f.
C. macrostylis W.V. Fitzg.
C. marginata W.V. Fitzg.
C. patersonii R.Br.
C. sericea Lindl.
Diuris laxiflora Lindl.
D. longifolia R.Br.
D. purdiei Diels
Elythranthera brunonis (Endl.) A. S. George
Leporella fimbriata (Lindl.) A. S. George
Lyperanthus nigricans R.Br.
Microtis atrata Lindl.
Paraceleana nigrita (Lindl.) Blaxell
Prasophylum cyphochilum Benth.
P. hians Reichb. f.
P. drummondii Reich. f.
P. macrostachyum R.Br.
P. ovale Lindl.
P. parvifolium Lindl.
Pterostylis nana R.Br.
P. vittata Lindl.
Thelymitra antennifera (Lindl.) Hook. f.
T. flexuosa Endl.

PHILYDRACEAE:

Philydrella pygmaea (F. Muell.) Car. (*Pritzelia pygmaea* (R.Br.) F. Muell.)

POACEAE:

Amphipogon turbinatus R.Br.
Danthonia occidentalis J. Vickery
Neurachne alopecuroidea R.Br.
Polypogon tenellus R.Br.
Sporobolus virginicus (L.) Kunth.
Stipa compressa R.Br.
S. hemipogon Benth.
S. variabilis Hughes

RESTIONACEAE:

Anarthria gracilis R.Br.
A. laevis R.Br.
Hypolaena exsulca R.Br.
Lepidobolus preissianus Nees
Leptocarpus aristatus R.Br.
L. canus Nees
L. coangustatus Nees
Lepyrodia macra Nees
Loxocarya fasciculata (R.Br.) Benth.
L. flexuosa (R.Br.) Benth.
L. pubescens (R.Br.) Benth.
Lyginia barbata (*L. tenax* (Labill.) Gardn.)
L. aff. barbata
Restio nitens Nees
R. sphacelatus R.Br.
R. tremulus R.Br.

XANTHORRHOEACEAE:

Acanthocarpus preissii Lehm.
Calectasia cyanea R.Br.
Dasypogon bromeliifolius R.Br.
Lomandra caespitosa (Benth.) Ewart
L. endlicheri (F. Muell.) Ewart
L. hermaphrodita (C. Andrews) C. A. Gardner
L. micrantha (Endl.) Ewart
L. preisii (Endl.) Ewart
Xanthorrhoea gracilis
X. preissii Endl.

ANGIOSPERMAE—DICOTYLEDONAE:

AIZOACEAE:

Macarthuria australis Hueg.

AMARANTHACEAE:

Ptilotus drummondii (Moq.) F. Muell.

APIACEAE: (UMBRELLIFERAE)

Actinotus leucocephalus Benth.
Eryngium pinnatifidum Bunge
Homalosciadium homalocarpum (F. M. Muell.) H. J. Eichler
Hydrocotyl callicarpa Bunge
Schoenolaena tennior Bunge
Trachymene pilosa Sm.
Xanthosia huegelii (Benth.) Steud.

ASTERACEAE: (COMPOSITAE)
Angianthus pygmaeus (A. Grey) Benth.
A. strictus (Steetz.)Benth.
A. tenellus (F. Muell.) Benth.
Brachycome pusilla Steetz.
Chrysocoryne drummondii A. Gray
Cotula coronopifolia L.
C...pratense
Craspedia uniflora G. Forster
Helichrysum bracteatum (Vent.) Andr.
Helipterum cotula (Benth.) DC.
Isoetopsis graminifolia Turcz.
Lagenifera huegelii Benth.
Olearia sp.
Podolepis gracilis R.Grah.
P. nutans Steetz
Podotheca angustifolia (Labill.) Less.
P. chrysantha (Steetz) Benth.
P. gnaphaloides Grah.
Quinetia urvillei Cass.
Siloxerus filifolius (Benth.) Ostenf. (*Angianthus fili-folius* (*Benth.*) C.A. Gardn.)
S. humifusus Labill. (*A. humifusus* (Labill.) Benth.)
Trichocline sp.
Waitzia paniculata (Steetz) F. Muell. ex Benth.

BYBLIDACEAE:
Byblis gigantea Lindl.

CALLITRICHACEAE:
Callitriche stagnalis Scop.

CASUARINACEAE:
Casuarina fraseriana Miq.
C. humilis Otto et Dietr.

CHENOPODIACEAE:
Halosarcia halocnemoides (Nees) P. G. Wilson, comb. nov. (*Arthrocnemum halocnemoides* Nees)

CLOANTHACEAE: (VERBENACEAE)
Pityrodia uncinata (Turcz.) Benth.

CONVOLVULACEAE:
Cuscuta epithymum L.
Wilsonia backhousii Hook.

CRASSULACEAE:
Crassula colorata (Nees)Ostf.
C. recurva (Hook. f.) Ostf.

DILLENIACEAE:
Hibbertia aurea Steud.
H. huegelii (Endl.) F. Muell.
H. hypericoides (DC.) Benth.
H. racemosa (Endl.) Gilg.
H. stellaris Endl.

DROSERACEAE:
Drosera bulbosa Hook.
D. erythrorhiza Lindl.
D. gigantea Lindl.
D. glanduligera Lehm.
D. heterophylla Lindl.
D. leucoblasta Benth.
D. macrantha Endl.
D. menziesii R.Br.
D. neesii Lehm.
D. occidentalis A. Morrison
D. palacea DC.
D. pallida Lindl.
D. stolonifera Endl.
D. zonaria Planch.

EPACRIDACEAE:
Andersonia aristata Lindl.
A. gracilis DC.
A. sprengelioides R.Br.
Astroloma pallidum R.Br.
A. stomarrhena Sond.
Conostephium pendulum Benth.
Leucopogon conostephioides DC.
L. oxycedrus Sond.
L. polymorphus Sond.
L. propinquus R.Br.
L. pulchellus Sond.

L. racemulosus DC.
L. squarrosus Benth.
Lysinema ciliatum R.Br.
Needhamiella pumilio (R.Br.) L. Watson

EUPHORBIACEAE:
Monotaxis grandiflora Endl.
Phyllanthus calycinus Labill.
Poranthera microphylla Brongn.

FABACEAE: (PAPILIONACEAE)
Bossiaea eriocarpa Benth.
Burtonia conferta DC.
Daviesia incrassata Sm.
Dillwynia cinerascens R.Br.
Euchilopsis linearis (Benth.) F. Muell.
Emaxia virgata Benth.
Gompholobium tomentosum Labill.
Hovea trisperma Benth.
Isotropis cuneifolia (Sm.) Benth. ex B. D. Jackson
Jacksonia floribunda Endl.
J. furcellata (Bonpl.) DC.
J. lehmannii Meisn.
J. sternbergiana Hueg.
Kennedya prostrata R.Br.
Oxylobium capitatum Benth.
Sphaerolobium medium R.Br.
Viminaria juncea (Schrad & Wendl.) Hoffmans.

GENTIANACEAE:
Villarsia albiflora F. Muell.

GOODENIACEAE:
Anthotium humile R.Br.
Dampiera linearis R.Br.
Goodenia caerulea R.Br.
G. filiformis R.Br.
Lechenaultia expansa R.Br.
Scaevola canescens Benth.
S. longifolia De Vries
S. paludosa R.Br.
Velleia trinervis Labill.

HALORAGACEAE:
Gonocarpus pithyoides Nees (*Haloragis pithyoides* (Nees) Benth.)

LAMIACEAE:
Hemiandra pungens R.Br.

LAURACEAE:
Cassytha flava Nees
C. micrantha Meisn.

LENTIBULARIACEAE:
Polypompholyx multifida (R.Br.) F. Muell.
P. tenella (R.Br.) Lehm.
Utricularia inaequalis A.DC. (*U. hookeri* Lehm.)
U. menziesii R.Br.
U. violacea R.Br.

LOBELIACEAE:
Isotoma hypocrateriformis (R.Br.) Druce
I. pusilla Benth.
Lobelia alata Thunb.
L. gibbosa Labill.
L. tenuior R.Br.
Monopsis simplex (L.) E. Wimm.

LOGANIACEAE:
Mitrasacme paradoxa R.Br.

LORANTHACEAE:
Nuytsia floribunda (Labill.) R.Br.

MALVACEAE:
Selenothamnus squamatus (Nees) Melville (*Plagianthus squamatus* (Nees) Benth.)

MIMOSACEAE:
Acacia huegelii Benth.
A. pulchella R.Br.
A. saligna Wendl. (*A. cyanophylla* Lindl.)
A. stenoptera Benth.
A. lasiocarpa Benth.

MYRTACEAE:

Astartea fascicularis (Labill.) DC
Baeckea camphorosmae Endl.
Beaufortia squarrosa Schau.
Calothamnus lateralis Lindl.
C. aff. villosus R.Br.
Calytrix aurea Lindl.
C. flavescens A. Cunn.
C. fraseri A. Cunn.
Aremaea pauciflora (Endl.) Druce
Eucalyptus calophylla R.Br.
E. rudis Endl.
Hypocalymna angustifolium Endl.
H. robustum Endl.
Kunzea micrantha Schau.
K. vestita Schau. (*K. ericifolia* Reichb.)
Leptospermum ellipticum Endl.
Melaleuca bracteosa Turcz. (*M. fasciculiflora* Benth.)
M. hamulosa Turcz.
M. lateriflora Benth.
M. lateritia A. Dietr.
M. preissiana Schau. (*M. parviflora* Lindl.)
M. rhapiophylla Schau.
M. scabra R.Br.
M. seriata Lindl.
M. uncinata R.Br.
M. viminea Lindl.
Regelia ciliata Schau.
Scholtzia involucrata (Endl.) Druce
Verticordia acerosa Lindl.
V. densiflora Lindl.
V. drummondii Schau.
V. huegelii Endl.
V. lindleyi Schau.
V. plumosa (Desf.) Domin.

POLYGALACEAE:

Comesperma virgatum Labill.

PORTULACEAE:

Calandrinia corrigioloides (F. Muell.) Benth.
C. granulifera Benth. (*C. pygmaea* F. Muell.)

PRIMULACEAE:

Samolus junceus R.Br.

PROTEACEAE:

Adenanthos cygnorum Diels
Banksia attenuata R.Br.
B. grandis Willd.
B. ilicifolia R.Br.
B. littoralis R.Br.
B. menziesii R.Br.
B. telmatiaea A. S. George
Conospermum huegelii R.Br.
C. stoechadis Endl.
C. triplinervium R.Br.
Dryandra nivea (Labill.) R.Br.
Grevillea thelemanniana Hueg.
Hakea candolleana Meisn.
H. ceratophylla (Sm.) R.Br.
H. prostrata R.Br.
H. sulcata R.Br.

H. varia R.Br.
Persoonia augustiflora Benth.
P. saccata R.Br.
Petrophile linearis R.Br.
P. longifolia R.Br.
P. macrostachya R.Br.
P. media R.Br.
P. seminuda Lindl.
Stirlingia latifolia (R.Br.) Steud.
S. simplex Lindl.
Synaphea petiolarie R.Br.
S. spinulosa (Burm. an.) *Merrill* (*S. polymorpha* R.Br.)

RUBIACEAE:

Opercularia vaginata Labill.

RUTACEAE:

Boronia viminea Lindl.
Eriostemon spicatus A. Rich.

SANTALACEAE:

Leptomeria empetriformis Miq.

SAPINDACEAE:

Dodonaea ceratocarpa Endl.

STACKHOUSIACEAE:

Stackhousia brunonis Benth.
S. huegelii Endl.

STYLIDIACEAE:

Levenhookia preissii (Sond.) F. Muell.
Stylidium amoenum R.Br.
S. brunonianum Benth.
S. bulbifera Benth.
S. calcaratum R.Br.
S. canaliculatum Lindl.
S. carnosum Benth.
S. dichotomum DC.
S. diuroides Lindl.
S. divaricatum Sond.
S. ecorne (F. Muell ex Erickson & Willis) comb & status nov.
S. guttatum R.Br.
S. inundatum R.Br.
E. obtusatum Sond.
S. perpusillum Hook. f.
S. petiolare Sond.
S. piliferum R.Br.
S. pulchellum Sond.
S. repens R.Br.
S. roseo-alatum Erickson & Willis
S. schoenoides DC.
S. striatum Lindl.
S. utricularioides Benth.

THYMELAEACEAE:

Pimelea imbricata R.Br. var. *gracillima* Meisn.
P. sulphurea Meisn.

The Silvereye (*Zosterops lateralis*: Aves: Zosteropidae): a review

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Abstract

Silvereyes have been pests of fruit crops since the last century but research to combat the problem has been minimal. They have a catholic diet with most documented items being arthropods from stomach contents. Nectar is an important food item in Western Australia because an abundant supply limits damage to crops of grapes. Migration in the eastern states is well known but only after the banding of more than 100 000 individuals. The banding of 36 000 in Western Australia has shown little evidence of systematic movements. The study of agonistic behaviour has suggested that aggressive behaviour is disadvantageous at feeding stations. Dominant individuals, however, survive better through winter and are more likely to breed. The study of a colour-banded population in New Zealand in 1939-40 provided information on breeding and territorial and vocal behaviour. Adult Silvereyes moult completely post-nuptially and partly pre-nuptially. Juveniles hatched early moult similarly but late-hatched juveniles' first moult is arrested and then the pre-nuptial moult is a complete moult. Variation in plumage colouration was first used to suggest the eastern migration and has been used with varying degrees of success to predict the sex of an individual. Body weight is lowest in the morning and 7% heavier in the late afternoon. Weight has been shown to be negatively correlated with daily air temperature and southern birds are heavier than northern ones. Maximum weight is attained during winter.

Introduction

Although Silvereyes are well known to amateur and professional ornithologists, many who have worked with them find them frustrating subjects to study because they are small, well camouflaged and secretive and, therefore, difficult to observe. In addition, the extent of our present knowledge is not great enough to allow an interpretation of some aspects of their biology that have been under investigation for some time. For instance, many amateur bird-banders in Western Australia are frustrated by the low recapture and recovery rate of their banded Silvereyes and by the fact that banded individuals do not seem to visit between banding stations that are as close as two km any more than between those that are 20 km apart. The resolution of such problems will undoubtedly take place as more data accumulates. In the meantime, it is valuable and encouraging to realise that many years of patient and dedicated work has provided substantial information about this animal. The purpose of this paper is to demonstrate that our knowledge of the Silvereye is greater than many may realise as well as to provide a basis for further research.

I have divided the information into seven sections: pest status, diet, movements, social behaviour, moult, colour variation and body weight.

Pest Status

Silvereyes have been well known to fruit growers in Western Australia ever since the days of the early settlements. Dalkeith Farm, described as a fruit garden extending along the Swan River and worked by James Gallop from 1877, was an important property to the new colony because of the produce it supplied to the north-west ports and Albany, as well as to Perth and Fremantle. By 1886 Silvereyes had become troublesome amongst the fruit and two Aborigines were employed to shoot the birds, more than 8 500 being shot in one year (Oldham and Williams 1980). Later, Aborigines were employed to frighten the birds away from the crops by beating kerosene tins with sticks (Hallack 1891, Oldham and Williams 1980). At least 20 000 Silvereyes were shot on this property and in another orchard near Bunbury 1 200 were shot in one day (Serventy and Whittell 1976, p. 403). Milligan (1904) claimed that 20 000 Silvereyes were often shot in a single orchard in a season.

Silvereyes were thought to be such a serious pest that in 1897 the Bureau of Agriculture proposed a bonus for their destruction of one shilling per 100 birds. The bonus was dependant upon a similar sum being paid by the Local Agricultural Societies (Anon. 1897).

In 1902 a deputation from the Bunbury district met with the Minister for Lands advising him of the considerable damage the Silvereye was causing to fruit in their area and that a recent meeting at Bunbury had resolved to ask the Minister to send an officer "to inquire into the habitat of the bird." They, too, wanted the Government to provide money for a bounty payment (Anon. 1902).

In 1904 a bonus of two shillings per 100 was proposed in a letter to the Minister for Lands by a frustrated fruit grower (Anon. 1904). He claimed that Silvereyes, as well as damaging fruit, destroy beneficial insects such as ladybirds which would otherwise have saved his citrus crop from a bad infestation of scale insects. Amongst his suggested methods for exterminating the species was that the Department's ornithologists should look to the possibility of parasitising the Silvereye. Milligan (1904) replied in defence of Silvereyes maintaining their usefulness in controlling insects that would otherwise be a problem. He proposed that a study be initiated to analyse the gut contents of Silvereyes to determine exactly what insects they do eat, as well as suggesting several methods to reduce the damage caused by Silvereyes to fruit. Newman (1924) supported the role of Silvereyes in maintaining the "balance of nature" by destroying unwanted insects. He claimed that the bulk of food found in the Silvereyes' stomachs was insects, particularly scales and aphids. He did not say if this latter claim was the result of the study proposed by Milligan (1904).

Apart from the limited use of a promising acoustic device developed by Knight and Robinson (1978a and 1978b), methods for controlling Silvereyes in fruit crops have advanced little from that of shooting to picking the crop early.

Diet

It is now well documented that Silvereyes are insectivorous as first reported by Cleland (1911 and 1912) and later summarised (Cleland *et al.* 1918). Matthiessen (1973) and Matthiessen and Springett (1973) found that Silvereyes ate arthropods of eight orders when they were feeding in and near potato crops in the Manjimup-Pemberton area of southwest Western Australia. The most common food was Lepidopteran larvae (mainly potato moth, *Phthorimaea operculella*), Coleopteran larvae and Hemiptera. In years when a particular food item was most abundant in the potato crops, that food item was found to be most common in the Silvereyes sampled. This shows that Silvereyes adjust their foraging behaviour to take the most abundant food item. In addition to this, Springett and Matthiessen (1975) showed that Silvereyes preferred to eat the larger fourth instar of the potato moth when larvae densities were low but, when larvae densities increased, the smaller third instar became increasingly attractive. This occurred despite equal abundance of both instars and indicates that Silvereyes respond to prey on a cost/reward basis. When prey numbers are low the birds prefer the larger items because the energy cost of capturing the smaller prey is too great with respect to the energy reward. When the prey is abundant no such preference is shown because the smaller items are common enough for their capture to require less energy expenditure.

In a New Zealand apple orchard, Moeed (1979) found that the food of Silvereyes in winter consisted of 14 orders of arthropods as well as earthworms, fruit and seeds. Lea and Gray (1936) and Rose (1973) also listed arthropods that they found in stomachs of Silvereyes.

It is generally known that Silvereyes have a wide range in diet, but little has been published on their diet other than arthropods. In South Africa the Yellow White-eye (*Zosterops senegalensis*) has been seen eating very strong red peppers that "pack a powerful punch" when added to a Chadian curry (Elliott 1977). Silvereyes regularly eat soft fruits, particularly grapes, in southern Australia and in late summer can be a nuisance in vegetable gardens eating such things as capsicums and tomatoes. In March, 1980, near Margaret River, Western Australia, two birds that I had banded were found in a bucket of milk where they had drowned, presumably whilst trying to drink the milk. Nectar is a favourite food of Silvereyes although confirming data is difficult to collect for such small birds.

Cage experiments have shown that they prefer sugar water more than various fruits (Rooke unpub.) and Ford (1979) reported observations of foraging Silvereyes that gave a ratio of nectar to insect feeding of 20:80. There is strong circumstantial evidence that Silvereyes have a preference for nectar over fruit. In southwest Western Australia, when the marri (*Eucalyptus calophylla*) produces large amounts of nectar during the fruit ripening season, Silvereyes are not seen in orchards and vineyards. Conversely, when the nectar crop is poor, Silvereyes cause great damage to the fruit (Robinson 1960, Rooke in prep.). Additional circumstantial evidence is that Silvereyes carry heavy loads of eucalypt pollen during times when marri flowers and the birds are absent from vineyards (Rooke unpub.). Observation of feeding as well as analysis of stomach content of Silvereyes in southwest Western Australia are showing the variety of food items taken. As well as 11 orders of arthropods, fruit or berries are taken from 18 species of plants, and nectar is taken from eight species (Rooke unpub.).

Hopper and Burbidge (unpub.) observed 57 plant species from which Silvereyes have been seen to eat nectar, berries, insects or seeds. Forty-nine of these are records of nectar feeding.

Table 1 summarizes the orders of arthropods that Silvereyes are known to eat.

Movements

My banding of Silvereyes around the Margaret River area of southwest Western Australia is indicating that the local population does not move far. Out of 11 000 birds banded so far only one has been recovered at a distance—at Manjimup 100 km ESE. All other recoveries have been within 50 km (Fig. 1).

Banding work at Middlesex near Manjimup, by Dick and Molly Brown has shown a few distant movements (one 267 km N, one 114 km NNE, two 100 km WNW) but other recoveries have been within 35 km (Dick and Molly Brown 1978-79;

Table 1

Orders of arthropods that Silvereyes are known to eat.

Order	Reference						
	1	2	3	4	5	6	7
Collembola					X	X	X
Blattodea						X	X
Orthoptera							X
Psocoptera						X	
Phthiraptera							X
Hemiptera	X	X	X	X	X	X	X
Thysanoptera	X					X	X
Neuroptera	X				X		
Coleoptera	X	X			X	X	X	X
Diptera	X			X	X	X	X
Lepidoptera	X	X	X	X	X	X	X
Hymenoptera	X	X		X	X	X	X
Pseudoscorpionidea						X	
Araneida	X	X	X		X	X	X
Opiliones						X	
Acarina	X					X	
Amphipoda						X	

1—Cleland *et. al.* (1918); 2—Lea and Gray (1936); 3—Rose (1973); 4—Matthiessen (1973); 5—Matthiessen and Springett (1973); 6—Mceed (1979); 7—Rooke (unpubl. data).
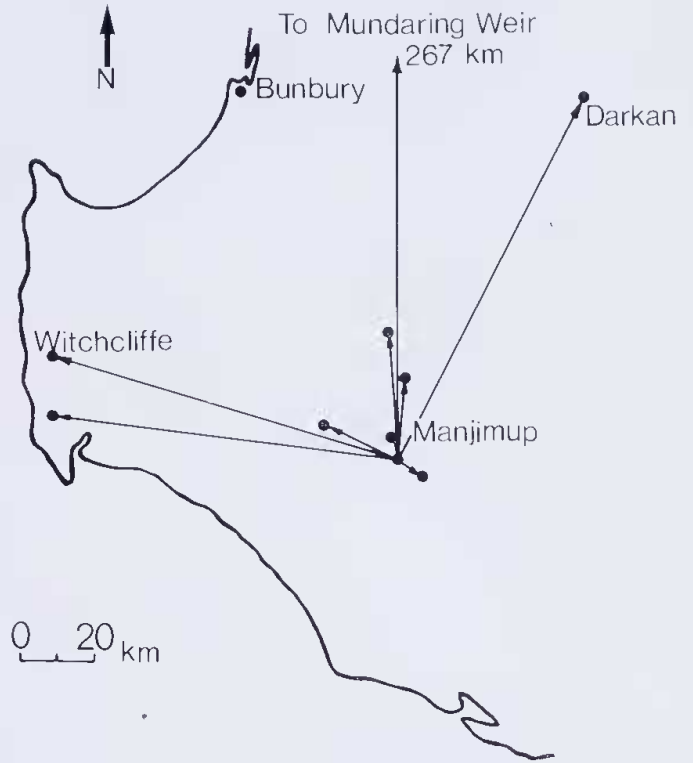

Figure 2.—Movements of Silvereyes from Middlesex, Western Australia. (from Brown 1978-9, 1979-80)
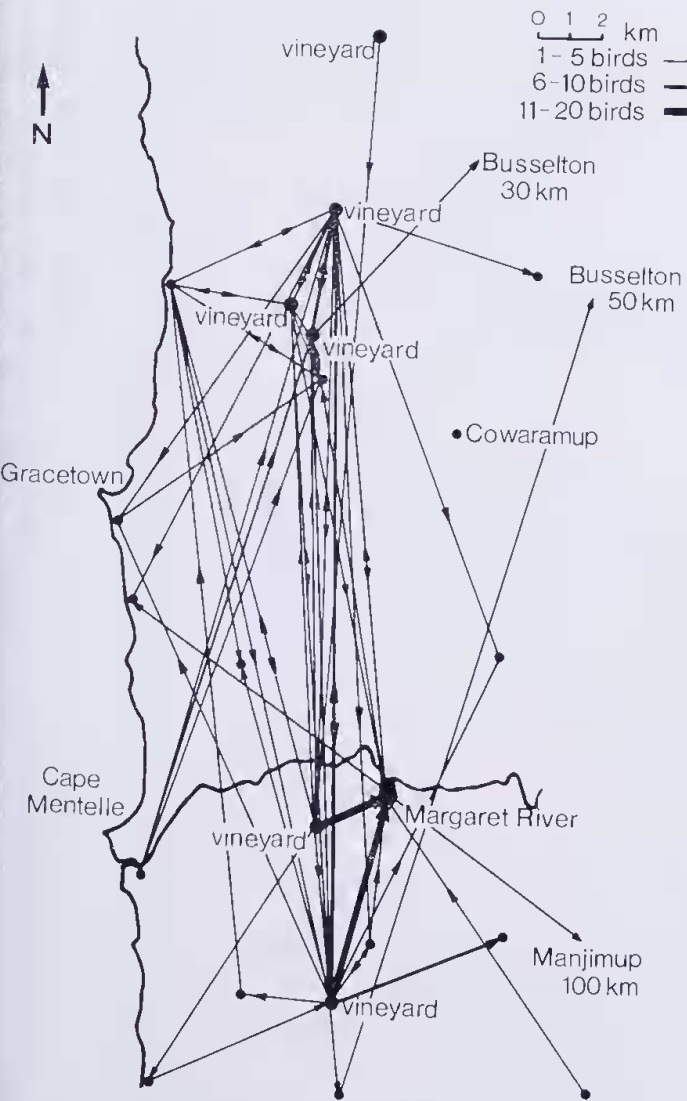

Figure 1.—Movements of Silvereyes near Margaret River, Western Australia. (Rooke unpubl. data)
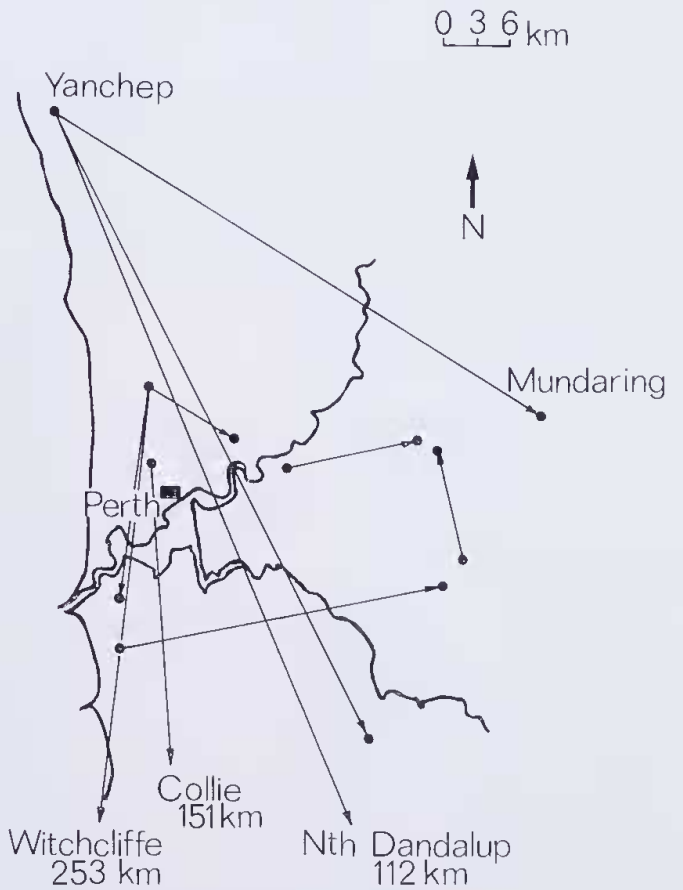

Figure 3.—Movements of Silvereyes from areas near Perth, Western Australia. (P. de Rebeira, unpubl. data)

1979-80) (Fig. 2). The Browns have banded approximately 10 000 Silvereyes but their efforts have failed to show any systematic movement.

Over the past 10 years, a number of people in and near Perth have banded approximately 15 000 Silvereyes. They have demonstrated several long movements of 100 to 300 km, all of which have been recovered south from where they were banded (Fig. 3). It may be that the birds which move south are a particular category of bird (e.g. juvenile) or perhaps recoveries have been made in the regions south rather than north of Perth because there are more settlements south and therefore more people to find banded Silvereyes. In addition to this, small flocks of Silvereyes have been observed moving southward along the coast in late summer. However, there is no evidence to suggest a return, northward movement (P. de Rebeira, pers. comm.).

Western Silvereyes may be more sedentary than some of their eastern counterparts, although such a conclusion may be rather hasty when viewed with the experience of the banding work in the eastern states. In 10 years, more than 100 000 birds were banded in the eastern states and the recoveries showing the long-distance movements amounted to only 75 (45 moving 50-300 km and 30 moving more than 300 km) (Lane 1972). This is a mere 0.00075% of the total birds banded and is a good example of the enormous effort required to substantiate such a phenomenon. Figure 4, from Hitchcock (1966, p. 11) shows some of these movements.

The idea of migration in eastern Australia was first suggested by Keast (1958) after he had noted the systematic arrival and departure of Tasmanian-type birds, as well as having caged Tasmanian-type birds to demonstrate that their plumage colouration was not changeable as proposed by others. Keast also noticed that the migration was partial because a considerable number of Silvereyes remained in Tasmania all winter.

Observations of Tasmanian-type Silvereyes in New South Wales during winter were also reported by Lane (1962a) and Swanson (1968) and in SE Queensland by Robertson (1971). The migration idea started to receive support by the movement of banded birds between Tasmania and the eastern coast of New South Wales (Lane 1962b, Liddy 1966). Substantial movement occurs at night, northward in autumn and early winter and southward in late spring/early summer (Lane and Battam 1971), although movement continues during the day at lower altitudes (Lane and Battam 1971, Vincent 1978). (Other progressive reports of the Co-operative Silvereye Project are listed in Lane (1972). Some individuals of the eastern Silvereye population, however, are sedentary (Bradley 1963, Liddy 1966, Swanson 1968, Lane 1972) and Lane (1972) suggested two discrete breeding populations one migratory and the other sedentary. The data do not support such a simple explanation for the Tasmanian-type Silvereyes, because some individuals migrate in some years but not in others (Mees 1974). In addition, it is not the juvenile class only that migrates because old birds constitute a large proportion of the migrants *(op. cit.)*.
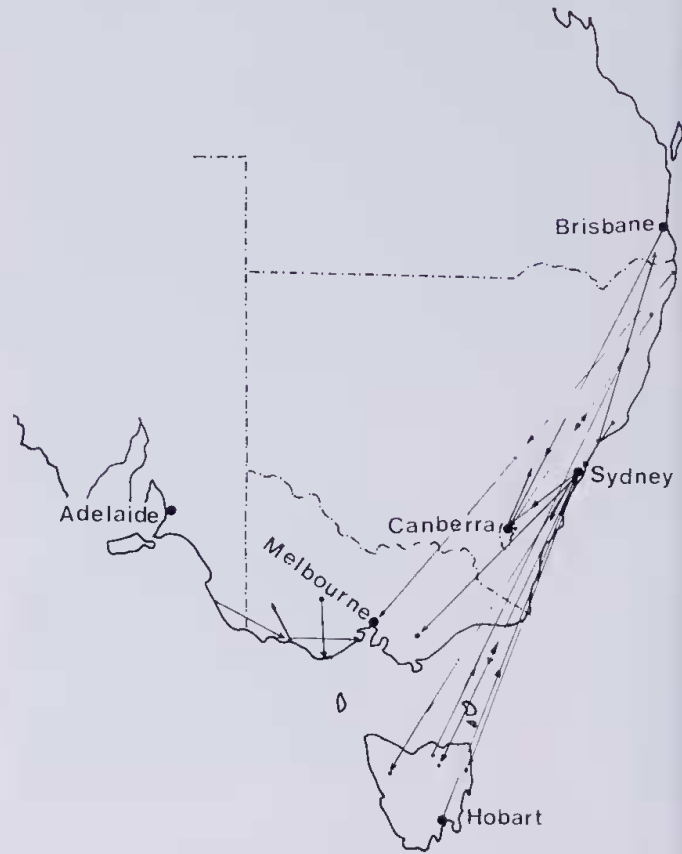

Figure 4.—Movements of Silvereyes in south-eastern Australia. (from Hitchcock 1966)

Fleming (1943) suggested that the Silvereyes in New Zealand do not migrate but that large winter flocks form from the aggregation of the breeding population of the district, and the flocks then disperse over a wider area. This conclusion is supported by the banding work reported by Marples (1944).

Localised movements may be made by particular age classes because Keast (1958) showed that only juvenile Silvereyes moved into vineyards near Sydney whilst the adults remained in the breeding areas. It remains to be shown that this phenomenon is more widespread.

Social behaviour

The social behaviour of Silvereyes has been studied in some detail in various locations by Kikkawa. At Dunedin, New Zealand, Kikkawa (1961) studied aggressive behaviour at a feeding station and in an aviary. He identified five types of aggressive behaviour which serve to establish and maintain the social hierarchy of a group but which, at a concentrated source of food such as the feeding station, seem to be disadvantageous both to the dominant and subordinant birds. Although there were numerous feeding stations in the Dunedin area which were likely to influence the natural population (Kikkawa 1960), Kikkawa (1961) argued that aggressive behaviour would be advantageous to the majority of birds in a less crowded situation.

The aviary birds behaved very aggressively when first caged or when new birds were introduced, but after two weeks of undisturbed occupancy, aggressive behaviour was reduced.

The study of the social hierarchy of winter flocks of Silvereyes was continued at Armidale, New South Wales (Kikkawa 1968). The birds showed the same agnostic displays as those in New Zealand and the southern migratory birds tended to dominate the locals as did males to females. The dominance hierarchy in caged birds did not appear to depend on the weights of the individuals. Territorial behaviour was induced by separating pairs into small cages and then when the small cages were connected, to allow free access to all birds, the original group social hierarchy was evident. This behaviour suggested that the social hierarchy of the winter flock may be important in determining the success of establishing a territory at the beginning of the breeding season.

A more detailed study of the agonistic behaviour of caged Silvereyes was undertaken by Williams *et al.* (1972). They used a numerical technique to analyse the postures of individual birds and, by so doing, were able to identify four of the five behavioural classes originally postulated by Kikkawa (1968), viz: the aggressive bird, the intermediate bird, the submissive bird and the inactive or subordinate bird. Their method failed to identify the dominant bird class. Their results suggested that agonistic behaviour of the flock is initiated largely by a single bird and perhaps influenced by humidity. The social hierarchy appeared to exist at two different levels; one stable hierarchy between groups of birds and another secondary level within each group that is weaker and changeable.

Kikkawa (1977) briefly summarised his earlier work on Silvereyes as a background to describing his work with Silvereyes on Heron Island, Queensland. Between 1965 and 1969 he colour-banded individuals at the beginning of each winter and recorded aggressive behaviour between them. With these data, and by censusing the birds at the end of winter, he found that dominant individuals survived better than submissive ones.

Additional work by Kikkawa and his postgraduate students (Kikkawa *et al.* 1975; Kikkawa 1977) showed that the population on Heron Island does not fluctuate markedly from year to year and, even when the population is severely reduced by cyclones, mortality of the remainder of the population is consequently reduced because of lowered competition for food. The population recovers to its previous density in the next breeding season.

Kikkawa and his students *(op. cit)* studied the breeding success of individuals of various behavioural categories and found that, in years of high density, significantly more pairs high in dominance nested and many first year birds, particularly submissive ones, failed to breed. Independent young were likely to be similar to their parents in dominance status.

The most recent report about the work on Heron Island Silvereyes (Kikkawa 1980) analysed in greater detail the survival through winter between 1965 and 1969 of individuals of different dominance classes. The results showed that socially dominant individuals were more likely to survive their first winter and that juveniles born earlier in the breeding season were more likely to be dominant. Body weight at the start of winter was not significant in affecting a bird's survival through winter. Dominant birds were considered to be more likely to survive because of their superior right of access to food.

Kikkawa's work emphasizes the important difference between dominance and aggressiveness. Dominant individuals (i.e. those that win agonistic encounters) are not always very aggressive and do not spend much energy fighting. On the other hand, aggressive individuals spend much time and energy fighting but but do not always win encounters.

The first published study of colour-banded Silvereyes was carried out in New Zealand by Fleming (1943). He worked mainly on his own property of 0.5 ha during 1939 and 1940. The breeding season was from mid-October until late February or early March with some pairs having three broods in one season. Some individuals and pairs used the same territory and nesting-tree in successive seasons although territorial behaviour did not exist during winter when the birds formed flocks that moved more widely. Fleming provided data about mating, nest-building, egg-laying, hatching, fledging, reproductive success and juvenile mortality. He studied some details of vocal behaviour and touched on the complexities of territoriality.

Moult

Swanson (1971) studied Silvereyes in her backyard in a Sydney, New South Wales, suburb and provided important details about the moult of free-flying birds. The main post-nuptial moult occurs from January to April and is a complete moult in adult birds and juveniles that are hatched early in the breeding season. Juveniles hatched later in the breeding season may commence moulting in their first autumn but this is arrested by the onset of winter and is completed before breeding in the following spring. The pre-nuptial moult of adult birds is mainly a replacement of head feathers. Swanson substantiated the earlier work of Keast (1956), the latter supporting his findings with details of the histology of the thyroid and experiments that demonstrated that changing day-length is the probable environmental factor affecting the timing of the moult. Marples (1945) found that Silvereyes in New Zealand also moult in spring and autumn.

Colour variation

Individual variation in the colour of plumage of Silvereyes has received some attention since Keast (1958) first used such a distinction to infer that Tasmania Silvereyes migrated to the mainland. Robertson (1972) analysed the colour of undertail, throat and flank of Silvereyes in Queensland, and found that the undertail colour decreases in intensity from northern to southern birds. Kikkawa (1963) found that the flank colour of Silvereyes in New Zealand could be used to determine sex, males having a darker or more reddish flank. He suggested that Australian Silvereyes could be sexed on the basis of the colour of the flank but this was not supported

by McKean (1965) or Mees (1969). Serventy and Whittell (1976) note that, for Western Australian Silvereyes, the male has brighter yellow on the throat than the female. My observations in the Margaret River area suggest that it may be possib.e to make such a distinction only if a known pair is being considered because the variation in intensity of the throat colour between males and between females is considerable.

Body Weight

The weights of New Zealand Silvereyes have been analysed on a seasonal and diurnal basis by Marples (1945). He found a diurnal weight fluctuation of 7% with the weight lowest in the early morning and heaviest in the late afternoon. The mean daily weight showed an inverse correslation with the mean daily air temperature. The New Zealand Silvereyes were heaviest in winter which is similar to the data obtained by Dick and Molly Brown (pers. comm.) near Manjimup, Western Australia. McKean (1965) suggested that southern Silvereyes may be heavier than more northern ones, but realised that the issue is complicated by the accumulation and/or expenditure of fat reserves by individuals that have migrated or may be about to migrate. Walker (1964) weighed Silvereyes at Turramurra, New South Wales and, identifying the origin of individuals on the basis of throat and flank colour, found that average weight increased from northern to southern birds.

Conclusion

A great deal of interesting and useful information has been accumulated about numerous aspects of the life of the Silvereye in the Australian and New Zealand regions. Whilst much of this work has been thorough and painstaking, it is clear that there are many unanswered questions.

We know little of the dynamics of the bird's natural food supply and its relationship to movements and consequent damage to crops. Aspects of the bird's physiology may demonstrate why it is such a pest in fruit crops. We know little of the reproductive potential, juvenile recruitment and actual population size, nor of how human agricultural practices affect the population. Studies are needed to determine the age structure of populations in various localities and habitats, to determine whether different classes of birds are involved in different activities. We do not know whether the adult breeding class ever interferes with human activities or whether it remains in natural, undisturbed areas. Answers to these types of questions would allow not only a better understanding of the population dynamics of the species but also a rational assessment of the conflict that this bird presents between agricultural productivity and conservation of natural resources.

We need to known much more about the basic biology of the Silvereye and, because the large number that have been banded suggests that the poulation is large, a concentrated effort by many workers together is likely to be successful in elucidating the broader issues.

References

Anon. (1897).—Extirpation of Vermin. *W.A. Agriculture, Bureau of Producers Gazette and Settlers' Record,* **4**: 1233-36.

Anon. (1902).—Bird Pests. *J. Agric. W.A.,* **5**: 169.

Anon. (1904).—Silvereyes. *J. Agric. W.A.,* **10**: 3-5.

Bradley, J. (1963).—Six years Silvereye banding—an analysis. *Bird Bander,* **1**: 93-97.

Brown, Dick and Molly (1978-79).—Middlesex Field Study Centre: Annual Report.

Brown, Dick and Molly (1979-80).—Middlesex Field Study Centre: Annual Report.

Brown, Dick and Molly (1980-81).—Middlesex Field Study Centre: Annual Report.

Cleland, J. B. (1911).—Examination of contents of stomachs and crops of Australia birds. *Emu,* **11**: 79-95.

Cleland, J. B. (1912).—Examination of contents of stomachs and crops of Australia birds. *Emu,* **12**: 8-18.

Cleland, J. B., Maiden, J. H., Froggatt, W. W., Ferguson, E. W. and Musson, C. T. (1918).—Food of Australian Birds. *Dept. Agric. N.S.W., Science Bulletin* **No. 15,** 112 pp.

Elliott, C. (1977).—Peppery Palates. *Bokmakierie,* **29**: 52-53.

Fleming, C. A. (1943).—Notes on the life history of the Silvereye based on color-banding. *Emu,* **42**: 193-217.

Ford, H. A. (1979).—Interspecific competition in Australian honeyeaters—depletion of common resources. *Aust. J. Ecol.,* **4**: 145-164.

Hallack, E. H. (1891).—Western Australia and the Yilgarn Goldfields. W. K. Thomas & Co., Adelaide. 34 pp.

Hitchcock, W. B. (1966).—Tenth annual report on bird-banding scheme. July 1963 to June 1964. *CSIRO Div. Wild. Res. Tech. Paper* **No. 11.**

Keast, J. A. (1956).—The moulting physiology of the Silvereye *(Zosterops lateralis)* (Aves). *XIV Intern-Zool. Cong.* Danish Science Press Ltd., Copenhagen.

Keast, A. (1958).—Races, colonisation and migration in the Silvereye. *Gould League Notes, (N.S.W.),* **24**: 10-13.

Kikkawa, J. (1960).—Wintering Silvereyes at bird tables in the Dunedin area. *Notornis,* **9**: 280-291.

Kikkawa, J. (1961).—Sociat behaviour of the White-eye *(Zosterops lateralis)* in winter flocks. *Ibis,* **103a**: 428-442.

Kikkawa, J. (1963).—A sexual difference in the plumage of the Silvereye, *Zosterops lateralis. Emu,* **63**: 32-34.

Kikkawa, J. (1968).— Social hierarchy in winter flocks of the Grey-breasted Silvereye *Zosterops lateralis* (Latham). *Japanese J. of Ecol.,* **18**: 235-246.

Kikkawa, J. (1977).—Ecological paradoxes. *Aust. J. Ecol.,* **2**: 121-136.

Kikkawa, J. (1980). Winter survival in relation to dominance classes among Silvereyes *Zosterops lateralis chlorocephala* of Heron Island, Great Barrier Reef. *Ibis,* **122**: 437-446.

Kikkawa, J., Wilson, J. M., Wyatt, W. S., Catterall, C. and Henderson, L. J. (1975).—Processes of selection in the population of *Zosterops* on a coral-cay island. *Emu,* **74**: 281.

Knight, T. A. and Robinson, F. N. (1978a).—A possible method of protecting grape crops by using an acoustical device to interfere with communication calls of Silvereyes. *Emu,* **78**: 234-235.

Knight, T. A. and Robinson, F. N. (1978b).—A preliminary report on an acoustic method for protection of crops from damage by Silvereyes *Zosterops lateralis* in south-western Australia. *CSIRO Div. Wildl. Res. Tech. Memo.* **No. 14,** 22 pp.

Lane, S. G. (1962a).—Notes on recoveries of Tasmanian type Silvereyes in Sydney. *Bird Bander*, **1**: 11.

Lane, S. G. (1962b).—Long distance recoveries of Silvereyes. *Bird Bander*, **1**: 12.

Lane, S. G. (1972).—A review of the co-operative Silvereye project. *Aust. Bird Bander*, **10**: 3-6.

Lane, S. G. and Battam, H (1971).—Silvereye movement in Eastern Australia. *Aust. Bird Bander*, **9**: 80-82.

Lea, A. M. and Gray, J. T. (1936).—The food of Australian birds—an analysis of the stomach contents. Part IV. *Emu*, **35**: 251-280.

Liddy, J. (1966).—A summary of Silvereye banding. *Aust. Bird Bander*, **4**: 71-73.

Marples, B. J. (1944).—Report on trapping and ringing work on the White-eye (*Zosterops lateralis*) throughout the Dominion. *N.Z. Bird Notes*, **1**: 41-48.

Matthiessen, J. N. (1973).—Observation on the food of some birds in southwestern W.A. *Emu*, **73**: 191-193.

Matthiessen, J. N. and Springett, B. P. (1973).—The food of the Silvereye, *Zosterops gouldi* (Aves: Zosteropidae), in relation to its role as a vector of a granulosis virus of the potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). *Aust. J. Zool.* **21**: 533-540.

Mees, G. F. (1974).—The migration of the Tasmanian race of the Silvereye. *Aust. Bird Bander*, **12**: 51-54.

McKean, J. L. (1965).—Weights of the Silvereye at Canberra. *Aust. Bird Bander*, **3**: 43-44.

Milligan, A. W. (1904).—Silvereys (*Zosterops gouldi*). Notes thereon and upon their suggested extermination. *J. Agric. W.A.*, **10**: 5-10.

Moeed, A. (1979).—Foods of the Silverey (*Zosterops lateralis* Aves) near Nelson, New Zealand. *N.Z. J. Zool.*, **6**: 475-479.

Newman, L. J. (1924).—Protection of useful insects, birds and animals. *J. Agric. W.A. (Ser. 2)*, **1**: 45-47.

Oldham, R. and Williams, A. E. (1980).—Inspection of Gallop House, Dalkeith. Royal W.A. Historical Society.

Robertson, J. S. (1971).—South-east Queensland aspects of the co-operative Silvereye project. *Aust. Bird. Bander*, **9**: 51-55.

Robertson, J. S. (1972).—Silvereye colour cline. *Aust. Bird Bander* **10**: 12-13.

Robinson, A. (1960).—The importance of the Marri as a food source to southwestern Australian birds. *W.A. Naturalist*, **7**: 109-115.

Rose, A. B. (1973).—Food of some Australian birds. *Emu*, **73**: 177-83.

Serventy, D. L. and Whittell, H. M. (1976).—Birds of Western Australia (5th ed.). Uni. W.A. Press, Nedlands, W.A.

Springett, B. P. and Matthiessen, J. N. (1975).—Predation on Potato Moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae) by the Western Silvereye *Zosterops gouldi* (Aves: Zosteropidae). *Aust. J. Zool.*, **23**: 65-70.

Swanson, N. (1968).—Suburban Silvereyes. *Aust. Bird Bander*, **6**: 5-7.

Swanson, N. M. (1971).—Moult in the Eastern Silvereye. *Aust. Bird Bander*, **9**: 75-80.

Vincent, J. (1978).—Diurnal movement of Silvereyes in East Gippsland, Victoria. *The Bird Observer* No. 564, p. 70.

Walker, D. M. (1964).—The relationship between plumage coloration, breeding location and body weight in the Silvereye (*Zosterops lateralis*). *Aust. Bird Bander*, **2**: 79-81.

Williams, W. T., Kikkawa, J. and Morris, D. K. (1979).—A numerical study of agonistic behaviour in the Grey-breasted Silvereye (*Zosterops lateralis*). *Anim. Behav.*, **20**: 155-165.